9. SEABED SURVEYS

9.1 Background

This chapter presents a summary of the seabed surveys conducted at sites where cuttings contaminated with SBFs (SBF-cuttings) have been discharged. Because more surveys have been performed and more detailed information has been collected at sites where WBFs (exclusively) have been discharged, results from WBF sites are also presented for comparison. The technical performance of SBFs is comparable to that of OBFs, and EPA is projecting that SBFs may be used as a replacement to OBFs more so than as a replacement of WBFs. However, as far as environmental effects of the discharge are concerned, EPA believes that SBFs are more comparable to WBFs. Also, WBFs are currently allowed for discharge in certain offshore and coastal areas, while OBFs (and OBF-cuttings) are not. For these reasons, EPA sees it fitting to compare the environmental effects of SBF-cuttings discharge with those of WBF and WBF-cuttings discharge.

The literature available to EPA for SBF discharge sites include studies performed in the Gulf of Mexico and in the North Sea. These studies have been performed both by regulatory bodies and/or industry groups. The results are available in the open literature. For WBF discharge sites, EPA used the Offshore Proposed Effluent Guidelines Regulatory Impact Analysis (Technical Support Document Vol. III; *Avanti* Corporation, 1993) as a source of information on field studies. This volume contains extensive lists of case studies on environmental impacts from oil and gas effluent discharges. Many of these studies were reviewed for information regarding seafloor and benthic impacts of water-based fluids and associated cuttings. In addition to this volume, additional citation searches for studies of the impacts of cuttings also were performed.

Materially, SBF wastes are different from WBF wastes in at least three important ways:

- Only SBF-cuttings are discharged, with retention of the SBF base fluid generally ranging between a low of 2 percent for the larger cuttings and a high of 20 percent for the smallest cuttings (fines). On the contrary, with WBFs, in addition to the WBF-cuttings, large volumes of WBF are also discharged. Thus, for an equal volume of hole drilled, the volume of WBF-related discharge is expected to be much greater than the volume of SBF-related discharge.

- WBFs contain very high levels of suspended and settleable solids (and are, in fact, referred to as “muds” in the industry) that disperse in the water column and produce a plume with many fine particles that settle rather slowly. Hence, they may be transported large distances. SBF-cuttings, however, tend not to disperse in the water column nearly to the same extent as WBFs because the particles are "oil" wet with the synthetic material. Even compared to WBF-cuttings, SBF-cuttings tend to be larger than WBF-cuttings. Again the reason is that SBFs do not disperse the cuttings particles to the same extent as WBFs. Because larger particles settle faster than smaller particles, SBF-cuttings tend to be deposited in a smaller impact area than WBF-cuttings.

- SBF-cuttings have a significant organic component that is not present in WBFs, namely the synthetic base fluid. The synthetic base fluid, in general, is insoluble in water and deposits in the sediment with the cuttings. Thus, compared to WBFs, SBFs have an additional major pollutant factor. The synthetic base fluid may have both direct and indirect adverse effects. Direct effects include physical effects as well as chemical toxic effects to benthic or epibenthic organisms. Indirect effects include both the effects on organisms that feed on these benthic organisms and the effects of anoxic/hypoxic sediment conditions from degradation of synthetic base fluids (due to their oxygen demand in local sediment).

These differences are important in making the comparison between SBF and WBF discharges, as is presented in the following sections.

9.2 Assessment of Field Studies

9.2.1 *Findings*

A large number of field studies of environmental impacts of exploratory well drilling discharges[1] in several offshore locations provide sufficient information to arrive at reasonably reliable findings for WBF seabed impacts. In contrast, existing data for SBFs are limited and do not appear to be sufficient to reliably project potential impacts. The different SBF studies used sampling designs that are incompatible and have methodological limitations (e.g., seasonal variability issues) that reduce the analytic clarity. Further field research is required to adequately characterize offshore impacts of synthetic-based fluid discharges.

Water-Based Fluids

The case studies reviewed by EPA characterize drilling fluids and cuttings dispersion, sedimentation, impacts on the sediment and benthos, and some of the potential factors influencing the magnitude of impacts. Exhibit 9-1 summarizes the major impacts of each of the reviewed studies. This review suggests that these discharges are capable of producing localized

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[1] Studies of development operations are much more limited in both number and scope (e.g., there are no pre- versus post-drilling surveys). Therefore, conclusions of impacts for WBFs are considerably more uncertain for development drilling than for exploratory drilling.

Exhibit 9-1. Marine Studies of Water-Based Drilling Fluid Impacts

Study Source	Study Site/ Location	Water Depth (m)	Impacts (a)	
			Sediment	Biota
Menzie et al., 1980; Mariani et al., 1980	NJ 18-3 Block 684 Mid-Atlantic Continental Shelf	120	• 21 fold increase in Ba at 1.6 km • 3.6 fold increase in Pb at 200 m • 2.5 fold increase in Ni at 100 m • 4 fold increase in Vn at 100 m • increased percentages of clay size particles within 1.6 km • cuttings piles observed	• within 150 m: 1. burial of sessile mega-benthos and macrobenthos; 2. lowest values of species diversity; 3. lower numbers of species • Ba increase in tissue at 1.6 km: mollusks: 20 fold polychaetes: 40 fold brittlestars: 133 fold
Houghton et al., 1980; Lees and Houghton, 1980	Cook Inlet C.O.S.T. well Alaska Continental Shelf	62	• cuttings (1.34 mm dia.) and 20% increase in sediment Ba conc. 400 m north of platform; • no piles	• substantial decrease in number of organisms from pre- to during and post-drilling at both 100 m and 200 m
Ray and Meek, 1980; Meek and Ray, 1980	Tanner Bank California Continental Shelf	63	• most cuttings fell within 50 m, fine cuttings within 100 m - 200 m of the discharge source; • mud on cuttings washed off during settling; • no piles	ND
Zingula, 1975	South Timbalier Block 172 Louisiana Continental Shelf	33.5	• below discharge point: cuttings covered by normal marine sediments 8.5 months after drilling cessation	• below discharge point: same abundance of fauna in cuttings samples as in “normal” sea bottom at 8.5 months
US DOI, 1977	Mustang Island Block 792 Texas Continental Shelf	36	• cuttings observed at four 100 m and one 500 m station • 2.5 fold increase in Ba during drilling at 1,000 m	• specimen abundance significantly decreased along 100 m periphery; • effect to 1,000 m
CSA, 1986	East Breaks Area Block 166 Gulf of Mexico	76 - 160	• 7.5 fold increase in Ba and 60% increase in Cr at 4 km • 2 fold increase in % Fe at 500 m	ND
Boothe and Presley, 1989	Northwest Gulf of Mexico	30 m; 100 m	• Ba increase within 500 m; 2.3-11 fold for all 6 sites • Pb increase within 500 m; 3.8 fold for 1 site • Hg increase within 250 m; 4-7 fold for 2 sites	ND

Exhibit 9-1. Marine Studies of Water-Based Drilling Fluid Impacts (Continued)

Study Source	Study Site/ Location	Water Depth (m)	Impacts (a)	
			Sediment	Biota
CSA, 1988	Gainesville Area Block 707 Florida Continental Shelf	21	• increase in Ba:Fe ratio: 90% at 4,000 m • increase in Cr conc: 11% at 300 m	• absence of seagrass within 300 m • growth inhibited beyond 300 m to 3.7 km. • 77% decrease in seagrass leaf count at 3.7 km • burial of live bottom communities at 25 m
CSA, 1989	Pensacola Area Block 996 Gulf of Mexico	50 - 60	• almost 3 fold increase in Ba and Ba/Fe ratio at 2,000 m	• reduced bryozoan coverage within 2,000 m of discharge
CSA and Barry Vittor & Assoc., 1989a,b	Alabama State Waters	40 - 60	• 2 to 5 fold increase in Ba at 1,000 m	• elevated As in oysters behind barrier islands
Bothner et al., 1985	Georges Bank Block 312 Block 410 Atlantic Continental Shelf		• 25% of barite deposited within 6 km • Ba transport detected at 35 km • cuttings observed within 500 m at Block 312 • cuttings observed at 2 km station at Block 410	ND
Steinhauer et al., 1990	Santa Maria Basin California Continental Shelf	90 - 410	ND	• sediment flux related to decreased soft coral coverage • statistical power of study limited to 70% or greater
Northern Technical Services, 1981	Beaufort Sea RIST Well Alaska Coastal	8	• cuttings accumulation observed: @ discharge pt: 5-6 cm @ 3 m: 2-3 cm @ 6 m: 1-2 cm @ 30 m: <0.5 cm • elevated Co, Cu within 50 m	• decrease in number of organisms 3 months after discharge

ND = no data

(a) Results presented represent a range of time periods relative to active drilling. Some surveys were conducted while drilling was ongoing; others took place many years after drilling ceased. For greater detail than presented in this summary, please refer to the individual study summaries that follow.

impacts but do not document larger-scale impacts. However, these studies are not sufficient to conclude that regional-scale impacts are not occurring.

Field studies of drilling fluid discharge plumes indicate that, as a generalization, plume dispersion is sufficient to minimize water quality impacts and water column toxicity concerns in energetic, open marine waters, such as the domestic OCS.

In shallow water areas (e.g., less than 5-10 meters), field data on plume dispersion are minimal, and are insufficient to conclude that water column effects present only a minor potential concern. Some modeling data suggest water quality and toxicity parameters could be adversely affected under shallow water conditions. Also, in water depths of less than 5 meters, the reliability of most models that are suitable for application to drilling fluid discharges becomes questionable. Thus, the potential water column impacts of those discharges in shallow waters (<5 meter) is not known with any degree of confidence.

The degree of impact of drilling fluids and cuttings on benthic and demersal species is highly dependent on a number of local environmental variables (e.g., depth, current and wave regimes, substrate type) and on the nature and volume of the discharges, including cuttings size and the location of the outfall in the water column. Impacts can be considered to fall into two relatively distinct categories: short-term effects due to either toxicity or burial by drilling fluid and/or cuttings; and longer-term effects due to chemical contamination or physical (textural) alteration of the sediments.

For example, Cook Inlet and Tanner Bank sites are both characterized as having strong currents. At these depths, currents significantly affect cuttings sedimentation patterns as well as cuttings transport along the bottom, entrainment and reworking of the sediment. Under these conditions, the investigators did not observe discrete cuttings piles which tend to form in more quiescent locations (Ray and Meek, 1980; Houghton et al., 1980). In the Gulf of Mexico, cuttings piles 150 m in diameter and 1 m in height have been reported (Zingula, 1975). On the other hand, cuttings seemed to be present at relatively farther distances in more energetic locations (Houghton et al., 1980; see below).

The extent of cuttings accumulation is important in assessing benthic impacts. A general trend of impacts is that specimen abundance decreased closer to the well. Several studies cited that the lowest numbers of organisms were at the 100 m stations, which were the closest stations to the well in these studies. Even in the dynamic location of Cook Inlet, authors reported that number of organisms and species diversity were significantly lower at the 100 m and 200 m sampling points than the control location (Lees and Houghton, 1980). These local effects have been ascribed to both physical changes in sediment texture and toxic effects. However, studies have not been designed to discriminate between these two potential causative factors.

The Cook Inlet Continental Offshore Stratigraphic Test (COST) well study was the only study reviewed that carefully analyzed sediment cores for the presence of cuttings as well as conducted chemical analyses. Barium concentrations in the sediment were found to be elevated in samples containing cuttings (defined by the authors as particles >0.85 mm) as far as 400 m from the platform (Houghton et al., 1980). These analytical results suggest that some drilling fluid still adheres to the cuttings and is transported and redistributed together with the cuttings. This is in contrast to the study in which divers observed drilling fluid being washed from the cuttings as the cuttings dropped through the water column within several meters of the outfall, although this latter observation was visual in nature (Ray and Meek, 1980).

The most clearly documented point source effect of these discharges has been alterations in sediment barium (Ba), a tracer for drilling fluids solids. Observations on sediment alterations from field studies of both single-well and multiple-well facilities include:

- Increases in Ba levels of 2-fold to 100-fold above background at the drill site, with typical values of 10-fold to 40-fold
- Average measured background levels are reached, statistically, at 1,000-3,000 m; single transect values have been elevated at up to 8,000 m
- Increases in Ba fall off logarithmically with distance from the drill site; regression analyses indicate background levels are achieved at 2,000-20,000 m.

Increases in a suite of other trace metals associated with drilling fluids (As, Cd, Cr, Cu, Hg, Pb, Zn) have also been observed. These increases:

- Are of a lower magnitude than seen for Ba (generally not more than 5- to 10-fold above background)
- Are more spatially limited, when compared to background levels, than seen for Ba (generally withing 250-500 m of the drill site, although increases at 1,000-2,000 m have been noted)
- Are noted consistently as a group, but are variable for any specific metal among the various studies.

Observations on the long-term, regional scale fate of drilling fluid solids indicate that the materials may be very widely dispersed over large areas. Dispersion is related directly to bottom energies of the receiving water (more shallow waters being more energetic than deeper waters).

- In shallow water (13-34 m) Boothe and Presley (1989) found that only about 6% of discharged Ba was accounted for within a 3 km radius of three drill sites in northwestern Gulf of Mexico; in contrast, for three drill sites in deeper waters (76-102 m) within the same study, the authors found 47% to 84% of the discharged Ba was found within a 3 km radius

- At these same six sites, Ba concentrations 3 km from the drill sites ranged from 1.2 to 2.9 times predicted background at the shallow water sites and at the deep water sites ranged from 2.0 to 4.3 times predicted background (Boothe and Presley, 1989)

- Drilling fluid solids can be transported over long distances (35-65 km) to regional areas of deposition, albeit at low concentrations, based on a study of eight wells (Bothner et al., 1985).

Biological effects have routinely been detected statistically at distances of 200 m to 500 m. Less routinely, effects have been observed at greater distances (1-2 km). These effects more typically are found to fall into one of two categories: those that are statistically significant at the level of individual stations but cannot be integrated into an easily defined pattern or those that are not statistically significant at the level of individual stations but do form significant correlations at larger levels of integration. Specific observations are as follows:

- The most affected community appears to be seagrass communities. Data on seagrasses are limited to a single study, but it documented damage much more severe than in any other study to date. Approximately 9 weeks after the drilling operation commenced, seagrasses were completely absent within 300 m of the drill site; at a distance of 3.7 km from the drill site, leaf biomass and leaf numbers showed only a 25% increase compared to the increases shown at the reference station (CSA, 1988).

- Fauna also have been affected, including changes in abundance, species richness (number of species), and diversity. Taxa include annelids, mollusks, echinoderms, and crustaceans.

- Alterations to benthic community structure are virtually always observed within 300 m of the drill site. However, changes have been noted in some cases at 500-1,000 m, and a few reports indicate alterations have occurred at 1-2 km.

- Changes have been ascribed to purely physical alteration in sediment texture and to platform-associated structural effects (i.e., from the fouling community) more frequently than to toxic effects. These causes are plausible, but there are not systematic studies of their relative contribution to observed impacts. Also, alterations due to physical causes may not be any less adverse than those due to toxic pollutants, and may be more persistent.

- Bioaccumulation has been observed for a suite of metals (Ba, Cd, Cu, Hg, Ni, Pb, V), but the magnitude of this effect is usually low (i.e., less than a factor of 5).

Synthetic-Based Fluids

The extent of the literature on field studies of impacts from discharges of SBFs is much more limited than for impacts from discharges of WBFs. EPA has identified and reviewed five studies, totaling six sites, for this environmental assessment. A summary of the results are provided in Exhibit 9-2. Others survey sites, and additional surveys at some of these same six sites also exist. However, difficulties occurred in trying to review this additional information: some studies are only available in Norwegian while others are proprietary or confidential in nature. The results of the five studies reviewed also present variability in terms of assessing the potential for adverse impacts from SBFs. This limited and varied information base makes drawing any generally applicable conclusions a difficult, and potentially unreliable, endeavor.

One study on the domestic continental shelf, in 39 m of water in the Gulf of Mexico, discharged a relatively small amount (354 bbl) of PAO SBF adhering to the drill cuttings (Candler et al., 1995). At a maximum, this amount represents approximately 45 metric tons of discharged olefins, which compares to North Sea discharges of approximately 100 - 180 metric tons of synthetic base fluid at each of three study sites. The top 2 cm of sediment were sampled at stations only out to 200 m, with 2,000 m reference stations. Synthetic base fluids, as measured by total petroleum hydrocarbons (TPH), showed substantial (60% - 98%) decreases between the first and second sampling surveys (i.e., after 8 months) at all but the closest, 25-meter station. How much of this decrease was due to biodegradation, as opposed to sediment redistribution and reworking, is uncertain. Although the data are somewhat difficult to interpret, it appears that little further reductions in TPH occurred between the second and third surveys (a 16-month period). This finding for a PAO synthetic base fluid contrasts with North Sea data on ester- and ether-type synthetic base fluids that indicate a continuing decrease in synthetic fluid over time. Limited analysis of benthos (the third survey only) indicated significant differences in the diversity scores at 25 m and 50 m stations compared to reference stations.

For three North Sea study sites, EPA reviewed the impacts from the discharge of SBFs. At a well site (K14-13) in the Dutch sector located at a depth of 30 m, approximately 180 metric

Exhibit 9-2. Marine Studies of Synthetic-Based Drilling Fluid Impacts

Study Source	Study Site/ Location	Type of Synthetic Base Fluid	Water Depth (m)	Cuttings/Synthetic-Based Fluids Discharged	Impacts	
					Conc. of Base Fluid in Dry Sediment (mg/kg)	Biota [a]
Candler et al., 1995	NPI-895 Gulf of Mexico Continental Shelf	polyalpha-olefin (PAO)	39; shunted	441 bbl cuttings plus 354 bbl adhering fluids; estimated at <45 metric tons of PAO	134,428 @ 50 m[b] 2,850 @ 50 m[c] 3,620 @ 50 m[d] 1,460 @ 200 m[b] 297 @ 200 m[c] 280 @ 200 m[d]	Not Available (NA) NA Abundance/Richness depressed @ 50 m[d]
Daan et al., 1996	K14-13 North Sea/ Dutch Continental Shelf	ester	30; shunted to 5 m above seabed	361 m^3 synthetic-based fluids; ≈ 180 metric tons of ester	706 @ 75 m[e] 393 @ 75 m[f] 84 @ 75 m[g] 300 @ 125 m[e] 834 @ 125 m[f] 10 @ 125 m[g] 54 @ 200 m[e] 161 @ 200 m[f] 55 @ 200 m[g]	NA Abundance/Richness depressed @ 200 m[f]; Richness depressed @ 500 m Abundance/Richness depressed @ 200 m[h]
Smith and May, 1991; Schaanning, 1995	Ula 7/12-9 North Sea/ Norwegian Continental Shelf	ester	67	749 metric tons cuttings containing 96.5 metric tons synthetic ester	85,300; 46,400; 208 @ 50, 100 and 200 m[e] 0.21, 0.22, and 1.34 @ 50, 100 and 200 m 0.38 (max.) @ 200 m	Abundance/Richness depressed @ 100 m[e] No Impact[h] No Impact[i]
Bakke et al., 1992 (in Norwegian, as cited in Schaanning, 1995)	Gyda 2/1-9 North Sea	ether	NA	160 metric tons synthetic ether	2,600 @ 50 m[j] 14,700 @ 50 m[h] 3.7 @ 50 m[d] 236 @100-200 m[j] 96 @100-200 m[h] 2.1 @100-200 m[d]	Reported as "Remarkably weak" (only 4 stations sampled)
Aquaplan, 1996 as cited in Vik et al., 1996	Eldfisk	PAO	NA	1,155 metric tons	79.8 @ 2,000 m	NA
Gjøs et al., 1995 as cited in Vik et al., 1996	Tordis	PAO	181-218	57 metric tons	8,920 @ 500 m 82 @ 1,000 m	NA

Exhibit 9-2. Marine Studies of Synthetic-Based Drilling Fluid Impacts (Continued)

Study Source	Study Site/ Location	Type of Synthetic Base Fluid	Water Depth (m)	Cuttings/Synthetic-Based Fluids Discharged	Impacts: Conc. of Base Fluid in Dry Sediment (mg/kg)	Impacts: Biota [a]
Gjøs, 1995 as cited in Vik et al., 1996	Loke	ester	76-81	180 metric tons	93 @ 250 m[e] 5 @ 500 m[e] 10 @ 250 m[h] 5 @ 500 m[h]	NA
	Sleipner A	ester	76-81	399 metric tons Petrofree	50 @ 250 m[e] 20 @ 500 m[e] 25 @ 250 m[h] <5 @ 500 m[h]	NA
				236 metric tons Finagreen	400 @ 250 m 30 @ 500 m	NA
	Sleipner Ø	ester		380 metric tons Petrofree	2,500 @ 250 m 250 @ 500 m	NA
Gjøs et al., 1992 & 1993 as cited in Vik et al., 1996	Gyda 2/1-9	ether	70	160 metric tons	2,600 @ 50 m[j] 420 @ 100 m[j] 150 @ 200 m[j] 14,700 @ 50 m[h] 50 @ 100 m[h] 25 @ 250 m[h]	NA
Johansen, 1996 as cited in Vik et al., 1996	Heidrum	acetal	342-375	208 metric tons	618 @ 500 m[h] 33.3 @ 1,000 m[h]	NA
Larsen et al., 1995 as cited in Vik et al., 1996	Ula 2/7-29	acetal	67	130 metric tons	56,888 @ 50 m[k] 10,000 @ 100 m[k] 2,368 @ 200 m[k] 2,000 @ 50 m[h] 2,000 @ 100 m[h] 1,000 @ 200 m[h]	NA
Feldstedt, 1991 as cited in Vik et al., 1996	Ula 7/12-A6	acetal	67	230 metric tons	650 @ 200 m[f] 156 @ 500 m[f] 18 @ 1,000 m[f]	NA

Exhibit 9-2. Marine Studies of Synthetic-Based Drilling Fluid Impacts (Continued)

Study Source	Study Site/ Location	Type of Synthetic Base Fluid	Water Depth (m)	Cuttings/Synthetic-Based Fluids Discharged	Impacts	
					Conc. of Base Fluid in Dry Sediment (mg/kg)	Biota [a]
CSA (API) 1998, Gulf of Mexico Continental Shelf	Grand Isle 95A	internal olefin	61	1,394 bbl cuttings plus 1,315 bbl adhering fluids	23,000 @ 50 m[d]	NA
	S. Marsh Island 57C	linear alpha olefin and internal olefin	39	448 bbl cuttings plus 850 bbl adhering fluids	6,700 @ 50 m[g] 41 @ 100 m[g]	NA
	S. Timbalier 148 E-3	internal olefin	33	782 bbl cuttings plus 2,390 bbl adhering fluids	1,900 @ 50 m[l]	NA
LGL Ecological Research Assoc., 1998 Gulf of Mexico Continental Slope	Pompano	90% LAO 10% ester	565	6,263 bbl adhering fluids (prior to 1997 survey) 1,486 bbl additional fluids (prior to 1998 survey)	165,051 @ 75 m[m] 198,320 @ 75 m[n]	Polychaete densities 40 times higher than background; gastropod densities 3,000 times higher than background [n]

a Abundance = No. of organisms; Richness = No. of taxa
b 9 days post discharge (pd)
c 8 months pd
d 2 years pd
e 1 month pd
f 4 months pd
g 11 months pd
h 1 year pd
i 2 years pd; Schaanning, 1995
j immediately pd
k 3 months pd
l 10 months pd
m 1997 survey
n 1998 survey

tons of ester SBF (resulting from the discharge of approximately 477 tons of adherent synthetic base fluid) were discharged (Daan et al., 1996). Surveys occurred 1 month, 4 months, and 11 months after SBF discharges ceased. The synthetic base fluid was detected in the upper 10 cm of sediment to a distance of 200 m from the discharge site (which was the farthest distance sampled in the second survey). During the second survey, sediment ester levels appeared to increase, a phenomenon that the authors surmised was related to resuspension and transport of highly contaminated and heterogeneous sediment very near the discharge becoming spread out and more well-mixed over a larger area between surveys. Significant decreases of 65% to 99% in sediment ester levels occurred, however, between the second (4 month) and third (11 month) surveys. Effects on benthos were more extensive: for the second survey effects were noted at 500 m stations, with much more pronounced effects within 200 m. Benthic analyses from the third survey indicated significant effects occurred only to 200 m. Additionally, recolonization and recovery at 500 m to 3000 m stations were also noted as occurring within the study area after 11 months.

EPA reviewed results from a study of the discharge of 97 metric tons of an ester SBF in the Norwegian sector (Ula well 7/12-9) in a water depth of 67 m (Schaanning, 1995). Surveys were conducted immediately, one year, and two years after discharge ceased. Sediment ester levels fell dramatically, with both maximum values and average values within 1,000 m decreasing more than five orders of magnitude over the course of the study, and more than three orders of magnitude between the first and second surveys. Benthic organisms were severely impacted out to 100 m in the first survey (immediately) after discharge ceased. Evidence of minor macrobenthic community changes (no details provided) were cited two years after the discharge ceased.

EPA reviewed results from a study of the discharge of 160 metric tons of an ether SBF in the Norwegian sector at the Gyda well site 2/1-9 that were presented in Schaanning (Bakke et al., 1992; 1993 as cited in Schaanning, 1995). Schaanning reports results from three surveys, one in 1991, 1992, and 1993. Ether levels seemed to fall continuously, with mean ether levels decreased by factors of 2-fold and 10-fold for 1992 and 1993 compared to 1991. This degree of degradation is considerably less than that reported above for the ester SBF at the Ula well site. Schaanning interpreted these results as indicating that a lag phase occurred in the biodegradation of the ether base fluid. Benthos were analyzed only at four stations in 1993; no data were reported, although Schaanning states that Bakke et al. (1992) observed “remarkably weak” effects.

There is very little information upon which to base any broad conclusions about the potential extent of impacts from SBFs. It appears that biological impacts may range from as little as 50 m to as much as 500 m shortly after discharges cease to as much as 200 m a year later.

Ester SBFs appear to be more readily biodegraded in North Sea studies than an ether SBF; the Gulf of Mexico study suggests PAOs also are less biodegradable than esters. Also, although esters appear to be readily biodegraded, one study indicates the persistence of uncharacterized “minor” impacts on benthos after synthetic base fluid levels have fallen to reference levels. These limited data, however, are not entirely adequate as a basis for any reliable projections concerning the potential nature and extent of impacts from discharges of SBFs. However, the reported adverse benthic community impacts are expected, given the basic SBF and marine sediment chemistry, the level of nutrient enrichment from these materials, and the ensuing development of benthic anoxia. The extent and duration of these impacts are much more speculative. Severe effects seem likely within 200 m of the discharge; impacts as far as 500 m have been demonstrated. The initiation of benthic recovery seems likely within a year, although it also seems unlikely that it will be complete within one year. And the relative impacts of the various types of SBFs is speculative given the limited marine sediment applicability of available laboratory methods for assessing toxicity and biodegradability and the paucity of field data for laboratory versus field correlations.

Drilling Fluid Impact Comparison

As described in the preceding sections, the reviewed seabed surveys measured either sediment or biologic effects from discharges of either WBFs or SBFs. Specifically, indicators of drilling fluid impact of seabed sediments are determined by measuring drilling fluid tracer concentrations (as either barium or SBF base fluid) in the sediment at varying distances from the drill site in an attempt to determine fluid dispersion and range of potential impact. Another class of impacts frequently measured are benthic community effects. The purpose of these studies is to assess potential drilling fluid affects such as increased metals and/or anoxia on biota.

Exhibit 9-3 summarizes the major impacts arising from the discharge of WBFs and SBFs. The distance in which SBF tracers are detected (100 m to 200 m) is much less than that of WBF (400 m to 35 km). Likewise, the impact on the biologic community is not as far-reaching for SBFs (50 m to 500 m) as for WBFs (25 m to 2,000 m).

9.2.2 *Study Limitations*

One of the major limitations in comparing data between the seabed surveys was the inconsistency in sampling methodology that was used, both spatially and temporally. The reviewed studies were often conducted using a variety of different sampling methods. Spatially, sampling locations were determined or chosen in one of several ways. Some studies established monitoring sites located radially from the discharge point. Others chose the drilled well location as the hub of the radial or intersecting transects. The Candler seabed study used the four

Exhibit 9-3. Water-based and Synthetic-Based Drilling Fluid Impact Comparison

Studied seabed impact	Water-Based Fluids (a)				Synthetic-Based Fluids (b)			
	Sediment		Biota		Sediment		Biota	
	Fraction of studies noting impact (c)	Max range of impact	Fraction of studies noting impact (c)	Max range of impact	Fraction of studies noting impact (c)	Max range of impact	Fraction of studies noting impact (c)	Max range of impact
Elevated tracer conc. (d)	9/10	400 m - 35 km	1/1	1.6 km	4/4	100 m - 200 m	--	--
Negative community impact	--	--	7/8	25 m - 2000 m	--	--	4/4	50 m - 500 m

(a) A total of 17 water-based fluid seabed survey studies were reviewed.
(b) A total of 4 synthetic-based fluid seabed survey studies were reviewed.
(c) The fraction equals the number of studies noting an effect from the total number of studies measuring the corresponding impact.
(d) For water-based fluids the measured tracer in both sediment and biota was barium (see Exhibit 9-1); for synthetic-based fluids either total petroleum hydrocarbons or the synthetic fluid was measured (see Exhibit 9-2).

compass directions as the transects, whereas the Daan study used only two transects, the direction of which was determined by the prevailing water current (Candler et al., 1995; Daan et al., 1996).

In one study (Daan et al., 1996), results of the pre-discharge survey were the basis for changing the transect orientations from cross-bathymetric to isobathymetric orientation. This invalidates comparison between these survey years. In another study (Schaanning, 1995), two reference stations were reasonably located at 5-6 km distance from the well site. However, these reference stations also showed a clear temporal pattern in sediment Ba and total hydrocarbon (THC) levels that suggest potential drilling waste contamination. Specifically, reference station THC levels decreased from 2.3 mg/kg to 0.25 mg/kg, to 0.09 mg/kg over 1990, 1991, and 1992 surveys. Reference station barium levels decreased from 265 mg/kg to 78 mg/kg to 55 mg/kg over the same period. These results throw some doubt on the validity of the reference stations despite their appreciable distance from the drill site.

Other variations in sampling are the sampling point locations on each of the transects. For example, sampling stations in one study were located 100 m and 500 m from the discharge point (U.S. DOI, 1977). In another, sampling stations were located much closer, e.g., 25, 65, and 85 m (CSA, 1988). In addition, several seabed surveys of WBF discharge used underwater TV

(UTV) in which divers filmed the seabed. However, the UTV of locations where cuttings were noted were not necessarily the location of these sampling stations (CSA, 1988).

Sample collection protocols often varied between studies. For example, in the North Sea Ula Well site seabed study, only the top 1 cm of sediment was collected and analyzed for ester concentrations (Smith and May, 1991). Other studies have collected deeper sediment cores, e.g., from the upper 2 cm for the Gulf of Mexico study site, or from the upper 10 cm for the Dutch sector North Sea (K14-13) study sites. This difference in sampling protocol has led authors to different conclusions. In the Smith and May study, the authors concluded that because the SBF base fluid was no longer detected in the sediment seabed, recovery had occurred. Other authors have concluded that synthetic based fluid migrated deeper into the sediment, suggesting that vertical redistribution is occurring as well as horizontal migration and redistribution.

Temporally, sampling was conducted using many different time interval configurations. Several studies conducted a pre-discharge survey in order to collect background information on the site and as a comparison or control for the drilling impact assessment. However, not all studies conducted pre-discharge surveys. Instead, reference stations, often located at arbitrary distances from the discharge point or well were used. Often, the seasonality of the pre-discharge survey was not maintained in later post-discharge surveys. Biologic parameters such as abundance, species diversity, and species richness are particularly seasonally dependent. Though spatial reference stations provide relative data to that collected in the vicinity of the discharge point, a combination of pre-discharge and post-discharge sampling surveys during the same season provides a more accurate comparison.

Though most studies reviewed included at least one reference station within the study design, several studies, such as the Mustang Island, Texas study (U.S. DOI, 1977) did not collect samples from such a station. The importance of a reference station is to provide the background or control information against which changes can be measured. The absence of background data during each sampling event discounts environmental effects, such as the above mentioned seasonal effects impinging on a larger area.

Several studies, such as that in the Beaufort Sea conducted the pre-drilling survey in the early spring, the first post-drilling survey in late spring and the final survey in late summer (Northern Technical Services, 1981). Benthic community structure undergoes significant changes during the spring and summer as growth and development occurs. This is compounded by the Arctic location which has a very short but intense growing season. The authors in this study mention seasonal impacts as a source of data variability, however, they neither designed the study to account for this variability nor conducted an analysis of the developmental effect on the benthic community during the growing season. Instead, the lack of a decrease in values of abundance was interpreted as an indicator of no impacts by drilling effluents, rather than an indicator of potential interference in benthic growth (Northern Technical Services, 1981). The absence of a reliable temporal control results in a dependence on spatial reference station integrity, which may be compromised by discharge impacts or natural interstation differences.

Due to the importance of sampling methodology in influencing the type of results generated, the lack of a standard sampling protocol or methodology affects the level of confidence in the data. Therefore, data generated from different methods may not always be directly comparable.

Limitations were also found in data analysis and interpretation as presented by the authors. One issue was that of the treatment of data outliers. In the Candler synthetic-based fluid study, the mean total petroleum hydrocarbons (TPH) was used to represent the concentration of TPH in the sediments. However, a closer look at the raw data reveals one replicate sample with a large TPH concentration decrease and three replicates with a concentration increase. The presentation of average TPH in all replicates masks a potential trend demonstrating synthetic-based fluid transport.

Two issues related to data analysis concern the broader environmental field study problems of natural, sampling, and analytical variability as well as the statistical power of analyzing and interpreting the data gathered. Because of high levels of natural, sampling, and analytical variability and high costs inherent to marine field studies, the statistical power of such studies is limited. That is, in order to detect an effect that is statistically significant, the magnitude of the change in a given parameter ranges from “large” for chemistry data to “very large” for biological data. Many of the surveys reviewed concluded that the discharge of drilling fluids and cuttings do not produce an effect on biota or have shown statistically significant adverse effect only to a limited spatial extent, i.e, to several hundred meters. For example, the CSA, 1989 study at the Pensacola Block 996 states that “...only catastrophic, large scale changes (e.g., complete mortality) would be evident from these [observed photographic] data. Qualitative and quantitative visual data revealed that such mortalities did not occur.” Even in the Santa Maria Basin study, one of the most sophisticated and well-funded studies conducted, sampling at 60 photoquadrants per station per cruise resulted in the ability to statistically resolve 70% reductions or greater in coral coverage. This level of detectability gives some measure of definition to and confidence in the study’s conclusion that “No statistically significant changes were noted.”

In summary, the lack of standard sampling methodology, differing monitored and analyzed parameters and differing study purposes presented in the reviewed articles severely limits the ability to compare effects of WBF and SBF on the seafloor. However, realizing the data limitations, useful information can be extracted from the various studies and used in evaluating general trends and ranges of impacts.

9.3 Summary of Relevant Field Studies

9.3.1 *Water-Based Fluids*

Zingula, R.P. 1975. Effects of Drilling Operations on the Marine Environment. in: Conference Proceedings on Environmental Aspects of Chemical Use in Well-Drilling Operations, Houston, Texas, May 21-23, 1975.

The author described observations of cuttings piles in drilling and post-drilling sites in the Gulf of Mexico. According to the author, diver surveys and side scan sonar records have shown typical accumulation in the Gulf of Mexico to be approximately 150 feet in diameter (46 meters), with the outline being circular, elongate, or star burst, depending on currents. Maximum elevation of these piles immediately after drilling a well appears to be less than 3 feet (1 meter). Several months after drilling, the height of the cuttings piles is less than 6 inches. No specific observations were cited to support these data.

In 1971, cuttings piles were photographed while drilling occurred in South Timbalier Block 111. The water depth was approximately 80 feet (24 meters). Photographs were taken below the platform to illustrate “normal” bottom conditions and 70 feet downcurrent where cuttings were present. According to the author, mobile organisms such as crabs were moving around on top of the fresh cuttings piles.

In order to observe cuttings after cessation of drilling, a site was chosen in South Timbalier Block 172, which had not been drilled for 8-1/2 months. Water depth was 110 feet (33.5 meters). The first dive was to record “typical” bottom conditions in the Gulf, outside the area of any cuttings accumulation. The sea bottom consisted of a thin surface layer of very soft and unconsolidated mud, underlain by sticky clay with some sand. The bottom was highly burrowed, and there were numerous whole and broken mollusk shells.

The second dive identified a pile of cuttings. The surface was also highly burrowed, indicating the presence of numerous benthic organisms. In addition, there was a thin accumulation of very soft and unconsolidated mud, indicating that marine sediments are already covering the cuttings.

A sample was taken of the top two inches of sediment cuttings at the location of the second dive. The cuttings were somewhat rounded by partial disaggregation of the clays from the swelling due to seawater adsorption and possibly from abrasive current action. These clay chips also showed a brownish oxidation on the exterior, further evidence that the chips were undergoing weathering.

Fauna in the cuttings sample were compared to that found in the "normal" sea bottom sample. According to the author, both samples contained essentially the same fauna, and in essentially the same abundance. Present in both were nearly 30 species of foraminifera, more than 15 species of mollusks and micromollusks, several species of bryozoans (both free specimens and coating mollusk shells), echnoid spines, ophiuriod ossicles, crab fragments, etc.

Ray, J.P. and E.A. Shinn. 1975. Environmental Effects of Drilling Muds and Cuttings. in: Conference Proceedings on Environmental Aspects of Chemical Use in Well-Drilling Operations, Houston, Texas. May 21-23, 1975.

Diver observations of the benthic environment in the vicinity of a drilling platform were described by the authors. During cuttings discharge, the heavier cuttings fall straight to the bottom to add to the cuttings pile. According to the authors, there is no doubt that sessile benthic organisms which cannot move about are buried by the cutting pile.

In depths below the effects of wave action, the cuttings piles produce a hard substrate capable of supporting a diverse and large number of organisms. It must be noted that this study did not collect any sediment cores so that no accounting of the benthic community was taken, either pre- or post-drilling. The authors, however, concluded that there are no observable detrimental effects on the marine life beneath Gulf of Mexico platforms.

U.S. Department of the Interior. 1977. Baseline Monitoring Studies, Mississippi, Alabama, Florida, Outer Continental Shelf, 1975-1976. Volume VI. Rig Monitoring. (Assessment of the Environmental Impact of Exploratory Oil Drilling). Prepared by the State University System of Florida, Institute of Oceanography. Contract 08550-CT5-30, Bureau of Land Management, Washington, D.C.

A study was conducted to provide a pre-, during-, and post-drilling assessment of selected biological, chemical and geological aspects of the environment in the vicinity of an exploratory drilling well. The monitoring survey was centered on a drilling location near the north lease line of Mustang Island (Texas) Block 792. Water depth was approximately 36 m.

The sampling pattern was in the form of a wheel with eight spokes centered on the well. Sampling points were located at distances of 100, 500, and 1,000 m from the drill site along each spoke. Thus, there were a total of twenty-five sampling points, including the drill site before and after operations and twenty-four points during drilling.

For clay mineralogy and standard sediment parameter analyses, two sediment samples were collected from each station by a diver filling PVC cores with sediment. A 9.1-m semi-balloon trawl was towed at a speed of three to six km/hour to collect macroepifaunal samples from each of the sampling points for trace element and histopathological analyses. The low number of epifauna in the study site limited histopathological examination to specimens of only two species of nektonic shrimp. One sediment core sample was also collected by divers at each station. The core was then subsampled for foraminifera and the remainder of the core was archived.

The clay mineralogy of the bottom sediments consisted predominantly of smectite followed by illite and kaolinite. Smectite levels did not change throughout the study period, however, illite levels significantly increased, whereas kaolinite decreased during and after drilling. Sand, clay and $CaCO_3$ levels increased and silt levels decreased during drilling operations.

During the active drilling phase, the authors noted that drill cuttings were specifically observed at only four 100-m periphery stations and one 500-m periphery station. Drill cuttings were still observed at these same five stations in the after-drilling phase but were notably less abundant.

The foraminiferal community composition indicated a "stressed environment" prior to drilling operations, and drilling activities further increased the stress. Total and live specimen abundance in samples collected during drilling were significantly less than those in the pre-drilling samples. The greatest effect on specimen abundances occurred along the 100-m periphery, but adverse effects were demonstrated out to the 1000-m periphery. However, the authors did not state if the cores at 100 m where the benthic fauna were sampled included cuttings samples.

Ray, J.P. and R.P. Meek. 1980. Water Column Characterization of Drilling Fluids Dispersion from an Offshore Exploratory Well on Tanner Bank. in: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24,1980. API, Washington, DC.

From January to March of 1977, a drilling muds and cuttings discharge monitoring program was conducted from a semi-submersible drilling platform on Tanner Bank, 161 km west of Los Angeles, California. The drill site was located in 63 m of water. Discharges during the study were from a 0.3 m diameter pipe located at a depth of approximately 12 m below the surface of the water. Photographic records were made by scuba divers using 35 mm stills and 16 mm movies. Surveys of bottom conditions directly beneath the discharge and in adjacent areas were made from a research submersible. Observations and aerial photographs of plume characteristics also were made from helicopters.

Diver observations showed that as cuttings exit the discharge pipe, the materials simultaneously separate in three directions: upward, downward and horizontally. The heavier cuttings and some associated mud began an immediate vertical drop. Cuttings were often "glued" together by drilling mud and fell to the bottom as large aggregates. The authors hypothesized that this may be a mechanism for the transport of small quantities of undiluted drilling mud directly to the sea floor beneath the discharge point. However, the divers observed that much of the mud adhering to the cuttings was washed off as they fell through the water column. These lighter fractions dispersed horizontally under current influences.

Observations made beneath the platform and on the nearby reef from the research submersible showed no visible signs of mud or cuttings accumulation. The authors stated that due to the high energy water movements present on Tanner Bank, these results were not unexpected.

Meek, R.P. and J.P. Ray. 1980. Induced Sedimentation, Accumulation and Transport Resulting from Exploratory Drilling Discharges of Drilling Fluids and Cuttings on the Southern California Outer Continental Shelf. in: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24,1980. API, Washington, DC.

From January to March of 1977, a drilling fluids and cuttings discharge monitoring program was conducted from a semi-submersible drilling platform on Tanner Bank, 161 km west of Los Angeles, California. The drilling site was located in 63 m of water. The authors investigated sedimentation because of concerns that accumulations of sediments including cuttings could smother important biotic assemblages such as the relatively rare stylasterine hydrocoral, *Allopora californica*.

To evaluate the spatial and temporal distribution of settled solids, 19 sediment traps were placed at various distances around the exploratory drilling platform. In addition, 9 pre-operational, 45 operational, and 11 post-operational sediment grabs were taken at varying distances from the drilling platform to evaluate accumulation and transport of the settling materials. A pair of modified Van Veen samplers were used to capture undisrupted surface sediments. Both sediment and grab samples were analyzed for total solids and WBF trace element concentrations of barium, chromium, and lead using atomic absorption spectroscopy.

Over the 85-day study period, 2,854 barrels of muds and cuttings were discharged. Cuttings discharge accounted for approximately 96% or 825,530 kg of the total discharged solids. Based on particulate composition, water depths and currents, the largest cuttings falling at speeds of 10 cm/sec fell straight down and would not reach traps just outside the platform perimeter. An analysis of the materials collected from traps located at 65 m and 120 m downcurrent of the discharge source demonstrated that finer materials were captured at the 120 m trap as would be expected given lower settling velocities as particle size decreases. However, both traps captured some fine cuttings and mud components with low settling velocities (less than or equal to 1 cm/sec). This indicated to these authors that within 200 m of the discharge, some aggregation of fine particles has also occurred.

Based on cuttings fall velocities, the decreasing measured sedimentation rate with increasing distance from the source, and the conglomerate effect of flocculation of drilling fluid components, the authors stated that the vast majority of the solids unaccounted for most probably fell to the bottom within the 50 m radius directly beneath the platform. From direct observations made by divers and submersible craft during the course of this study, who noted the absence of cuttings piles, the authors concluded that the majority of these settled solids were resuspended from the sea bed and redistributed. The authors calculated from sediment trap and adjacent pre- an post-drilling grab data that 70 to 80% of the settled solids and components were transported.

Houghton, J.P., et al. 1980. Drilling Fluid Dispersion Studies at the Lower Cook Inlet, Alaska, C.O.S.T. Well. <u>*in*</u>*: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.*

This study presents results of oceanographic studies and measurements and modeling predictions of the fate of discharged fluids and cuttings in the environment. The Lower Cook Inlet Continental Stratigraphic Test (COST) well was drilled between June 7, 1977 and September 26, 1977 with the *Ocean Ranger* semi-submersible drilling vessel. The well was located in the central portion of Lower Cook Inlet approximately 57 km WSW of Homer, Alaska and 38 km ENE of Augustine Island. The water depth at the site was 62 m.

The physical marine environment in Cook Inlet is dominated by large tidal fluctuations and strong currents. The authors measured these oceanographic parameters. Mean and diurnal ranges were calculated to be 4.6 m and 5.3 m, respectively. Currents were measured at the COST well using current drogues and two arrays of Endeco 105 current meters. Current meter data indicated mean maximum flood currents of 52, 62, and 78 cm/sec for meters placed near the bottom, at midwater, and near the surface, respectively. Mean maximum ebb currents were 42, 68, and 104 cm/sec, respectively at similar depths.

The seabed in the COST well area was reported to be typically sand or gravel waves, with heights occasionally greater than 3 m. Sea floor reconnaissance at the well site and adjacent areas was conducted using UTV and various bottom samplers. The authors mapped the drilling mud plume upon discharge using a dye injected into the drilling effluent. In addition, plume modeling was conducted and results were compared to field data.

Bottom sampling and specially designed drilling effluent traps were used to define deposition of cuttings on the sea floor in the vicinity of the drilling vessel. Two specially designed drilling effluent traps were constructed to measure the potential deposition rates and their particle size distribution. One trap (T-2) was deployed approximately 2.9 km WNW of the *Ocean Ranger*; the other trap (T-1) was deployed 100 m NNE of the discharge point from the platform. Samples from the drilling effluent traps were passed through a 0.85-mm screen and the portion of the sample larger than 0.85 mm was examined under a microscope on a grain by grain basis for the presence of cuttings. Approximately 2.4 gm of cuttings were identified in T-1 giving a calculated deposition rate of 5.24×10^3 g/hr/m^2. No cuttings were identified in the control trap T-2.

Bottom samples were obtained with a Souter-Van Veen grab sampler at various locations near the drilling vessel. Core samples 8 cm in diameter were taken from the sampler, sectioned vertically at 0.5-cm intervals, then screened, and examined for cuttings (defined as particles greater than 0.85 mm in diameter). These analyses indicated that the sea floor was sufficiently mobile to entrain cuttings to a depth of at least 12 cm into the sea floor by the end of the well (approximately 3 months duration). The maximum cuttings percentage in the sediments identified in any bottom sample was less than 3 percent by weight and was found 100 m north of the discharge. Analysis for barium sulfate and barium showed that drilling mud was being carried to the sea floor with the cuttings. Though the authors do not state in the text, presented data indicate that 1.34 mm cuttings are found 400 m north of the platform with slightly elevated barium concentrations of 680 µg/g in the corresponding sediment sample. Background or pre-drilling barium sediment concentrations were 560 µg/g.

The authors concluded that the heavier cuttings material deposited on the sea floor was entrained vertically into the sediment since the sandy bottom was quite mobile. Benthic sampling, core analysis, and UTV examination verified that cuttings did not accumulate on the sea floor as a cuttings pile. In addition, the relatively low increase in sediment barium levels suggests that near-bottom currents agitate newly fallen cuttings with the natural sands exerting a washing action that cleanses cuttings of adhering barite.

Lees, D.C. and J.P. Houghton. 1980. Effects of Drilling Fluids on Benthic Communities at the Lower Cook Inlet C.O.S.T. Well. in*: Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.*

The major purposes of this study were to (1) determine species composition and abundance of the benthos in the area of the well site, and (2) evaluate the extent to which changes were attributable to drilling activities. The Lower Cook Inlet Continental Stratigraphic Test (COST) well was drilled between June 7, 1977 and September 26, 1977 with the *Ocean Ranger* semi-submersible drilling vessel. The well was located in the central portion of Lower cook Inlet approximately 57 km WSW of Homer, Alaska and 38 km ENE of Augustine Island. The water depth at the site was 62 m.

Benthic samples were obtained by Ponar grab samples before, during and at the conclusion of drilling operations. For each of the time periods, the number of species, species diversity, and number of organisms were evaluated for 10 stations, each at 100 m north, 200 m north, and the control located 1,700 m east of the drilling vessel.

Results are presented in Exhibit 9-4. The authors mentioned that the increase in the number of organisms and variation in the number of species and species diversity for the June, July and September time points (corresponding to before, during and after drilling) is most probably due to seasonal variations. However, the authors did not discuss that compared to the control location samples, the number of organisms had substantially decreased in the during- and post-drilling surveys at both the 100-m and 200-m locations.

Mariani, G., Sick, L., and Johnson, C. 1980. An Environmental Monitoring Study to Assess the Impact of Drilling Discharges in the Mid-Atlantic. III. Chemical and Physical Alterations in the Benthic Environment. in*: Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.*

The objective of this study was to characterize and determine chemical (trace metal) and physical (grain size, clay mineralogy) changes of the sediment. This study also analyzed tissue of three representative benthic taxa for trace metal content: brittle stars (primarily *Amphioplus macilentus*), molluscs (primarily *Lucinoma filosa*) and polychaetes.

Two benthic sampling surveys were conducted. A pre-drilling survey was conducted in July and August 1978 and a post-drilling survey was conducted in July 1979. The pre-drilling survey area comprised a 1.6 km radius around the well site while the post-drilling survey was extended to a 3.2 km radius.

Exhibit 9-4. Comparison of Sampling Area of Averages for Numbers of Species, Organisms, and Species Diversity for the Survey Periods

Survey Period	100-m	200-m	Control
	Mean number of species (S)		
June	9.9 ± 3.2 (a)	___	8.5 ± 3.1 (b)
July	9.0 ± 2.1	12.4 ± 2.5	17.5 ± 3.5
September	10.7 ± 1.6	11.3 ± 2.7	15.8 ± 5.7
	Mean number of organisms (N)		
June	35.1 ± 21.3[a]	___	43.3 ± 37.4[b]
July	28.2 ± 14.4	41.8 ± 9.9	80.0 ± 61.4
September	59.7 ± 29.9	41.4 ± 20.5	183.7 ± 110.4
	Mean species diversity (H)		
June	2.10 ± 0.4[a]	___	1.51 ± 0.31[b]
July	1.98 ± 0.51	2.16 ± 0.48	2.70 ± 0.40
September	2.00 ± 0.23	2.17 ± 0.23	1.78 ± 0.54

(a) Based on samples 3, 4, 11, 16, 17, 18, 19 in the area of both 100-m and 200-m stations.
(b) Based on samples 28, 29, 30, and 31 about 1,000 m from Anchor Buoy 4 (AB-4).

Six samples were collected with a Smith-McIntyre or modified Ponar Grab at each station for the physical, chemical, and biological analyses. Upon retrieval of each grab, two sediment cores (one for sediment granulometry and one for trace metal analyses) were taken near the center of the grab.

The physical alterations that took place during the post-drilling survey included increased percentages of clay size particles within the immediate vicinity of the well site (46 meters) and extending out to approximately 800 meters. The increased percentages of clay within the sampling grid were accompanied by changes in proportions of clay minerals in the area. The authors stated that these changes in clay percentage and mineralogy suggest that fine materials were deposited around the well site during drilling operations.

Increases in the concentration of lead, barium, nickel, vanadium, and zinc for bottom sediments were detected during the post-drilling survey. The authors presented metals concentration data as a spatial distribution, highlighting the trend of metals in sediment concentrated around the drill site in the pre-drilling survey and distributed at low but fairly even concentrations to 1.6 km in the post-drilling survey. Barium concentration increased 21 fold at 1.6 km, lead increased 3.6 fold at 200 m, nickel increased 2.5 fold at 100 m, and vanadium increased 4 fold at 100 m.

Analysis of tissue samples of brittle stars, molluscs and polychaetes collected during the post-drilling survey revealed that each group had significantly higher barium and mercury content than tissue samples collected during the pre-drilling survey. The barium concentration in mollusks, brittlestars, and polychaetes collected at 1.6 km increased 20 fold, 133 fold, and 40 fold, respectively, whereas mercury concentration increased 4 fold, 18 fold, and 30 fold, respectively at the same distance. Increased mercury content was detected in these organisms despite the fact that data showed mercury concentrations in the sediment were below the detection limit of 0.05 μg/g, indicating that the mercury was bioaccumulating.

Menzie, C., Maurer, D., and Leathem, W. 1980. An Environmental Monitoring Study to Assess the Impact of Drilling Discharges in the Mid-Atlantic. IV. The Effects of Drilling Discharges on the Benthic Community. in: Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, Florida, January 21-24, 1980. API, Washington, DC.

The objective of this paper was to describe the short-term environmental effects of drilling fluids and drilled cuttings on marine benthos around exploratory well NJ 18-3, Block 684 on the Mid-Atlantic Continental Shelf. The study was conducted within two weeks following the termination of drilling. The leased block was located approximately 156 km off the coast of New Jersey and had an approximate water depth of 120 meters.

Two surveys were conducted to examine the abundance and composition of the benthic fauna in the vicinity of the well site. A pre-drilling survey was conducted in July and August 1978 and a post-drilling survey was conducted in July 1979. The pre-drilling survey area comprised a 3.2 km diameter area around the well site while the post-drilling survey was extended to a 6.4 km diameter area.

UTV surveys were conducted during the pre- and post-drilling surveys to provide information on the spatial distribution of megabenthic epifauna around the well site and to examine physical changes in the benthic environment resulting from drilling operations. Ten UTV transects (200-1,000 m in length) were made throughout the survey area during the pre-drilling survey, while 11 transects (150-900 m in length) were made during the post-drilling survey.

During the pre-drilling survey, 40 benthic stations were sampled, of which 22 were analyzed in a radial pattern around the well site, while during the post-drilling survey, 48 benthic stations were sampled, of which 41 were analyzed. The rest of the samples were held for later possible analysis. Six grab samples were collected at each station, of which two were analyzed for fauna while the remainder were held for future analysis.

Benthic samples were washed on a 0.5 mm mesh sieve to remove silt, clay, and fine sands. The material retained on the sieve was preserved with 10% buffered formalin-Rose Bengal solution. Macrobenthos were sorted from these samples and identified with the aid of stereoscopic and compound microscopes.

Seafloor UTV observations during the pre-drilling survey revealed a nearly featureless bottom topography interrupted by burrowing and feeding mounds of benthic invertebrates. During the pre-drilling survey, the sediments were comprised of medium-fine sands with a silt and clay content of 16-25%. During the post-drilling survey, bottom UTV observations revealed that sediments in the immediate vicinity (approximately a 75 m radius) around the well site were comprised of patches of drilling discharges (primarily semi-consolidated, natural subsurface clay materials) which altered the microtopography of the area. Mounds of this material were generally less than 10 cm in height. Debris (e.g., small pieces of pipe, tires, rope) was also observed in the immediate vicinity of the well site. Side scan sonar showed the bottom scour marks of anchor chains radiating out from the well site. Sediments in areas beyond the immediate vicinity of the well site appeared similar to those observed during the pre-drilling survey.

Fish (primarily hake, *Urophycis* spp.) and crabs (primarily *Cancer borealis*) increased substantially between pre- and post-drilling surveys in the immediate vicinity of the well. The authors speculated that these organisms may have been attracted to the region as a result of the increased microrelief afforded by the cuttings accumulations. High densities of sand stars were observed near the well site, apparently associated with accumulations of mussels (*Mytilus edulia*) that had fallen from the drilling rig and associated anchor chains.

Sessile megabenthos (pennatulids) and macrobenthos were subjected to burial by drilled cuttings within the immediate vicinity (i.e., within approximately a 75 m radius) of the well site.

Measures of species diversity, species richness, and species evenness obtained prior to the onset of drilling were high and relatively constant over the sampling area. Species diversity of macrobenthos collected during the post-drilling survey were within the general range observed for the shelf-break region, though some values were lower. The lowest values during the post-drilling survey were observed in the immediate vicinity of the well site (75 m). Lower numbers of species generally reflect the lower numbers of organisms observed at some stations.

Based on the patchiness in the distribution of the species and in density, the author hypothesized that the variability represented differences between plots in which the infauna had been buried by cuttings and those which had escaped burial or in which recolonization had occurred, but supporting data were not presented.

Differences in the nature of infaunal assemblages were particularly clear when pre- and post-drilling survey data for densities of major taxa were compared. Pooled densities of annelids, molluscs, echinoderms, and crustaceans were all lower in the post-drilling survey.

In summary, this study concluded that the discharge of drill cuttings caused local and at least short-term effects on the fauna in the vicinity of the well site. Increases and/or decreases in abundance were probably related mostly to: (1) physical alterations of the substrate (e.g., rapid deposition and burial, increased surface relief or increased clay content of the sediment), as well as (2) effects of predation by hake, crabs, and starfish. No toxic effects were identified.

EG&G Environmental Consultants. 1982. A Study of Environmental Effects of Exploratory Drilling on the Mid-Atlantic Outer Continental Shelf-Final Report of the Block 684 Monitoring Program. 1982. Prepared for Offshore Operators Committee. October 1982.

This survey is the second in a series conducted at the exploratory well site NJ 18-3, Block 684 on the Mid-Atlantic Outer Continental Shelf. This survey was taken one year after drilling operations had stopped at the site. Forty-one sites were sampled ranging from 23 m to 3.2 km from the discharge location. The study evaluated the fate of drilling fluids discharges based on: 1) percent clay, 2) trace metal concentration (Ba, Cr, V) in the sediment, and 3) benthos impacts (trace metal concentration in organisms and density of mega and marcobenthos). Analysis of this survey indicated the percent clay levels decreased from the drill site out to 800 m measured during the first study, to levels common with predrill levels. However, several patches of increased clays were measured out to 750 m. Because trace metal leachate levels measured in the first post-drill survey did not link to discharge characteristics provided by Ayers et al (1980), analysis for trace metals was limited to barium, chromium, and vanadium (Ba, Cr, V). Ba measurements from the second study indicate a shift in the Ba concentrations in the direction of the predominate current (southwest), with 3-fold increases above predrill levels measured to 400 m from the discharge point. There appeared to be an even distribution of megabenthos with respect to distance from the discharge point. All four dominant macrobenthos, although depressed below predrill densities, increased from densities found during the first post-drill survey. Species richness as with abundance increased from the first post-drill survey, however they did not reach predrill levels. Impacts were seen out to 1.2 km. These impacts were not, however, correlated to Ba concentration. Chromium in increased concentration from predrill levels was detected in polychaetes out to 1.2 km from the discharge point.

Northern Technical Services. 1981. Beaufort Sea Drilling Effluent Disposal Study. Prepared for the Reindeer Island Stratigraphic Test Well Participants. Under the direction of Sohio Alaska Petroleum Company. 329 pp.

Sohio Alaska Petroleum Company (SOHIO) completed the Reindeer Island Stratigraphic Test (RIST) well in Prudhoe Bay area of the Beaufort Sea in early 1979. A study was conducted to evaluate the effects of above- and below-ice discharges. At the time of the study, normal procedure for handling drilling mud and cuttings from offshore wells was to haul them to an onshore disposal site.

Test Plot 1 was the discharge location at a water depth of 8 m. Monitoring locations were oriented radially from the discharge point ranging from less than 5 m to 500 m distance from the discharge point. The control location was denoted as Test Plot 3 which was about 1 km south of Test Plot 1.

Results at Test Plot 1 indicated a strong sorting of materials by grain size. Larger particles were deposited closer to the discharge point while finer materials, including drilling muds, were deposited further away from the discharge point. Freshwater drilling muds readily flocculated upon discharge into seawater. According to the authors' observations, these flocs were loosely deposited on the seafloor during winter and could be resuspended with the slightest agitation.

The authors stated that it is likely that flocculation extends to cuttings since clay-sized particles in the drilling mud tend to coat cuttings during the drilling process and thus provide sites for attachment of other clay-sized particles.

Diver observations were conducted at Test Plot 1 on May 4, 1979, 4 days after the test discharge. A 5- to 6-cm thick accumulation of mud and cuttings was observed on the seafloor in the vicinity of the discharge point. UTV observations the following day indicated a 2- to 3-cm deposition at a distance 3 m east of the discharge point. The consistency of the deposited materials was such that materials would be suspended with the slightest agitation. At a distance of 6 m east of the discharge site, 1 to 2 cm of loosely deposited drilling effluents was observed. By a distance of 30 m east of the discharge, accumulation of drilling muds on the seafloor was estimated to be less than 0.5 cm thick. Organisms observed during the post-discharge survey at Test Plot 1 included amphipods, a snail, several fish and mysids, an hydroid, an anemone, numerous snail and isopod tracks, and numerous worm tubes.

Benthic sampling was conducted at Test Plots 1 and 3 prior to and subsequent to the test discharge of drilling effluents. All samples were obtained using a Petite Ponar bottom grab sampler. Fifteen random replicate samples were taken at each of the test plots during sampling periods on April 7-10, May 9, and August 3-4, 1979. For the April and May surveys, samples were obtained through holes augered in the sea ice in random 5 m by 5 m squares within each of the 50 m by 50 m test plots. For the August survey, randomness in samples was achieved by drifting in a boat within a 25 m radius of the center of the test plot.

Benthic data were analyzed and are summarized in Exhibit 9-5. The authors calculated the number of taxa, species diversity, evenness and species richness values by pooling the 15 replicate samples taken at each test plot during the sampling period.

Exhibit 9-5. Summary of Benthic Data Collected at Test Plots

Collection Date	Test Plot [a]	Abundance (no./m^2)	No. of Taxa	Shannon Function of Diversity	Even-ness	Species Richness	Biomass (gm/m^2 wet wt)
April 7, 1979	1	551.1	45	2.96	0.83	6.97	10.0
April 8, 1979	3	809.4	54	3.32	0.83	7.91	29.4
May 9, 1979	1	1240.0	63	3.11	0.75	8.70	33.9
May 9, 1979	3	1529.9	65	3.50	0.84	8.73	59.2
August 3, 1979	1	1202.7	67	2.94	0.70	9.30	18.4
August 3, 1979	3	2678.0	76	3.09	0.71	9.50	55.0

[a] Test Plot 1 refers to the discharge location and Test Plot 3 to the control location.

The authors did not seem to stress that the time difference in sampling is strongly affected by the natural growing season. As presented in Exhibit 9-6, from pre-drilling in April to immediately after discharge in May, there is a significant increase in the number of organisms per square meter (abundance) most probably due to the beginning of the growing season. From May to August, there is a 75% increase in abundance in the control location (Test Plot 3) and a 3% decrease in Test Plot 1. Though the authors do not present the percentage change nor the percentage difference between the control and test plot data, it is clear that in the time between May and August there should be a normal increase in numbers of organisms. This lack of increase in Test Plot 1 implies that the drilling discharges may have interfered with organism population growth during that time period.

Exhibit 9-6. Comparison of Abundance Data Collected at Test Plots

	April 7, 1979		May 9, 1979		August 3, 1979	
	1	**3**	**1**	**3**	**1**	**3**
Abundance	551.1	809.4	1240.0	1529.9	1202.7	2678.0
Increase from April to May Sample	---	---	125%	89%	---	---
Increase from May to August Sample	---	---	---	---	-3%	75%

Trace metal analysis was conducted on replicate Ponar and whole drilling mud samples in order to detect possible effects of below ice drilling effluent disposal. The majority of the bottom samples were obtained at random locations within 50 by 50 m of test plot 1 (the discharge site) and test plot 3 (control site). As indicated by analysis of the samples at each of the sites, variations of trace metals at the test discharge site was similar to variations found at the control location. According to the authors, these results of the trace metal analysis confirm that drilling muds are quite swiftly resuspended and removed from the seafloor after initial settlement.

Bothner, M.H. et al. 1985. The Georges Bank Monitoring Program 1985: Analysis of Trace Metals. U.S. Geological Survey Circular 988.

This study was designed to establish the concentration of trace metals in sediments prior to drilling on Georges Bank and to monitor the changes in concentrations that could be attributed to petroleum-exploration activities. The first cruise of the monitoring program occurred just before exploratory drilling commenced in July 1981, and nine subsequent cruises were conducted on a seasonal basis (November, February, May, and July) over a 3-year period. Eight exploratory wells had been drilled at that time on Georges Bank. The first was started on July 22, 1981, and the last well was completed on September 27, 1982.

Of 12 trace elements analyzed, only barium was found to increase in concentration during the period when the eight exploratory wells were drilled. The maximum post-drilling concentration of barium reached 172 ppm in bulk sediments near the drill site in Block 410. This concentration was higher than the pre-drilling concentration at that location by a 5.9-fold factor. No drilling-related changes in the concentrations of the 11 other metals were observed in bulk sediments at any of the locations sampled in the program. Analyses of sediment trap material for Ba-enriched matter showed that resuspension can occur up to at least 25 m above the seafloor.

The authors estimated that about 25 percent of the barite discharged at block 312 was present in the sediments within 6 km of the rig, 4 weeks after drilling was completed at that location. In their evaluation of the rate at which barite decreases within the site-specific survey, the authors considered only the area between the 0.5- and 2-km circles. They also excluded the actual drill site, where large within-station variability was measured. For almost a year following completion of the well, the inventory of barite decreased rapidly, with a half-life of 0.34 year. During the next year, the inventory decreased at a slower rate (half-life of 3.4 years).

To see how far Ba from drilling mud could be traced, the authors analyzed the fine fraction of sediment at two stations approximately 65 km west of the Block 312 drill site and at two stations approximately 35 km to the east of the easternmost drill site. At the two western stations they measured maxima in Ba concentrations during cruises 8 and 10 in 1983. The authors were surprised to find that maxima in the Ba concentrations, although of lower magnitude, were also recorded at similar times at the two eastern stations. The maximum value at one eastern stations on cruise 7 was statistically higher than the mean of the first 6 cruises at the 99.5 percent level of confidence (t test). These findings were considered significant because they suggested that Ba in the finest fraction of drilling mud may have been transported over very wide areas of the bank, to the east as well as to the west.

The barite discharged during the exploratory phase of drilling is associated with the fine fraction of sediment and was found widely distributed around the bank. Evidence indicated barium transport in the predominant, westerly current direction as far as Great South Channel (115 km west of the drilling), and to stations 35 km east of the easternmost drilling site, against the predominant current. Small increases in barium concentrations were measured also at the heads of both Lydonia and Oceanographer Canyons, located 8 km and 39 km, respectively, seaward of the nearest exploratory well.

Throughout the 3 years of monitoring , the concentrations of Ba in bulk sediments from the upstream control stations were fairly consistent with time. On the basis of those data, the authors judged that no increase in Ba had occurred at those stations. They found no increases in the concentration of other metals as a result of drilling at the upstream locations during the 3 years of monitoring. In contrast, there were measurable changes in the concentrations of Ba in Block 410 (stations 16, 17, and 18).

The scatter in their data indicated to the authors that Ba was not distributed homogeneously over the sampling area. This heterogeneity was probably caused by the intermittent discharge of drilling fluids into ocean currents that continuously change direction of flow throughout the tidal cycle. A few cuttings were found during both year 2 and year 3 at a station located 2 km to the east of the drill site, in Block 410. On cruise 9, cuttings were observed at all stations within 500 m of the drill site in Block 312.

At coring stations 50 km west of transect III, the authors observed an enrichment of the Ba/Al ratio in surface sediments and interpreted that as evidence for a small recent addition of Ba. A rough calculation referred to from an earlier report (Bothner et al, 1984) suggested that 69 percent of the barite discharged by all eight exploratory wells could be accounted for in the sediments within the western half of a circle 130 km in diameter and centered on station 5. They then concluded that the barite from drilling mud was associated with the fine-sediment fraction in low concentration and was widely distributed.

This study demonstrates that drilling fluid solids may be widely distributed over large areas in relatively short period of time if they are discharged in high energy marine environments such as the Georges Bank. Transport was observed over distances of 35 - 115 km, both in the anticipated direction of deposition and opposite that of predominant current flow. This study indicated that in such environments, assessing low-level, regional-scale contamination effects is the primary source of concern.

Neff, J. M. M. Bothner, N. Maciolek, and J. Grassle. 1989. Impacts of Exploratory Drilling For Oil and Gas on the Benthic Environment of Georges Bank. Marine Environmental Research 27 (1989).

This study was conducted over a three year period to determine the impact of discharges from exploratory drilling to benthic community of Georges Bank and was conducted in conjunction with the previous reviewed article by Bothner et al. (1985). The authors conducted benthic fauna analyses at 46 sample sites that included 31 sites adjacent to two drilling platforms. Sampling took place quarterly and pre-, during, and post-drilling. The authors indicated changes in the benthic communities near the platforms during and immediately after drilling activities, but attributed these changes to natural changes within the community populations.

Continental Shelf Associates. 1988. Monitoring of Drillsite A in the Gainesville Area Block 707. Prepared for Sohio Petroleum Company, Houston, TX, April 26, 1988. 124 pp.

The purpose of this study was to assess the environmental impacts of proposed exploratory drilling in Gainesville Area Block 707 on several seagrass and live-bottom communities. Gainesville Area Block 707 is located approximately 60 km from the west coast of Florida in water depths of 21 m.

Two surveys were conducted and results analyzed. Survey 1 was a pre-drilling survey. The drill rig moved onsite on May 25, 1984, and began drilling discharges on June 3, 1984. Survey 2 (August 9 - August 23, 1984) occurred during drilling. A third survey was also conducted, but because it followed a severe hurricane that disrupted the benthos across a wide area of the northwest Florida continental shelf, most of the results were not used.

According to other studies the authors referenced in this area, plant densities or bottom coverages within offshore seagrass and algae stands range from 20 to 50%. *Halophila* species comprise about 79% of the plant material present while various species of microalgae account for the remainder. *Halophila decipiens* was found to be the only seagrass species present in the vicinity of the Block 707 drill site.

Sampling stations were located within 300 m of the discharge point in a radial pattern. The closest stations were located 25 m, 65 m, and 85 m from the discharge. Live bottom monitoring stations were located 25 m and 500 m from the drill site and 3 reference stations were located greater than 9 km from the drilling operations. Six randomly placed quadrants were permanently established and photographed. An additional 10 stations were established beyond 300 m during survey 2.

During the second survey, visual observations revealed the absence of all seagrass within 300 m of the discharge site. An accumulation of cuttings around the discharge site was also observed, particularly along the northwest radial within 30 m of the discharge point. Farther from the drill site, growth was inhibited as a function of the concentrations of the two drilling effluent indicators, barium and barium:iron ratios in the fine-grained fraction (<63 µm) of surficial sediments.

To determine whether or not exposure to drilling effluents affected the seagrass, the authors evaluated the relationships between changes of the indicators of discharged drilling effluents and the changes in standing crop of the seagrass. The indicators of discharged drilling effluents were the barium concentrations and barium:iron ratios in the fine-grained fraction (<63 µm) of the surficial sediments. The fine-grained fraction was analyzed because barium sulfate in the discharged drilling effluents is in the silt/clay particle-size range and the sediments around the drill site were sand. Thus, metal concentrations in the fine-grained fraction were more efficient tracers of the settleable fraction of the discharged drilling effluents. Logarithmic transformations of the mean changes of these indicators were used in the correlation analysis.

The authors presented Ba:Fe ratio data as well as chromium concentration data. The data showed a 90% increase in the Ba:Fe ratio at 4,000 m from the discharge point and an 11% increase in the chromium concentration at 300 m.

Results of analysis indicated that there were statistically significant negative correlations between changes of the drilling effluent indicators and changes of the seagrass standing crop. Larger changes in drilling effluent indicators (e.g., increases in sediment Ba levels or of Ba:Fe ratios) were associated with smaller changes in seagrass standing crop (i.e., although seagrass standing crop increased, the magnitude of the change was negatively correlated to effluent indicators).

Both leaf biomass and leaf count increased from the pre-drilling to the during-drilling surveys, most probably due to the growing season. However, while leaf count increased 1,212% at the reference station, it only increased 282% and 84%, respectively, at the 4,000 m- and 1,300 m-stations (77% and 93% decreases in growth).

Impacts to the live bottom community at the 25 m station resulted primarily from burial of cuttings. The authors concluded that smothering by drilling muds and cuttings may have been important at distances close to the drill site. Farther from the drill site, reduction in the light levels reaching the seafloor as a result of increased turbidity in the water column was thought to be the primary factor.

Two follow-up surveys were conducted one year and two years after drilling. According to the authors, these surveys indicated seagrass recovery had occurred. However, data regarding the extent of recovery were not provided.

Boothe, P.N. and B.J. Presley. 1989. Trends in Sediment Trace Element Concentrations Around Six Petroleum Drilling Platforms in the Northwestern Gulf of Mexico. In: F.R. Englehardt, J.P. Ray, and A.H. Gillam (Eds.) Drilling Wastes. Elsevier Applied Science, London. pp. 3-22.

The goal of this study was to determine typical concentrations of drilling fluid residuals in surface and subsurface sediment within 500 m of six offshore drilling sites in the northwestern Gulf of Mexico. Three types of drilling sites were studied: exploratory sites as isolated as possible from other wells; developmental sites with multiple, recently completed wells; and production sites where considerable time had elapsed since drilling was completed. For each of the three types, a location was chosen in shallow water, i.e., about 30 m in depth and in deep water, i.e., about 100 m in depth. NOTE: In the authors’ use of the relative, descriptive terms “shallow” and “deep” in their report, the term “deep” (i.e., ~100 m) is not the same as the term used in reference to this rulemaking, for which “deep” wells are defined as those in waters greater than 1,000 m in depth.

Sediment was collected at 40 stations around each drilling site using a circularly- and radially-symmetrical pattern. Background concentrations were determined by analyzing sediments from 4 control stations located 3,000 m from each drilling site in addition to subsurface sediments located well below the possible influence of surface discharges (4-31 cm depth).

Barium mass balance data show that only a fraction of the total Ba, and presumably similar drilling mud components, are present in near-site sediments. At nearshore study sites, approximately 94% of the discharged Ba had been transported more than 3,000 m from the drilling sites. Offshore sites were more variable, showing transport beyond 3,000 m for 16%, 28%, and 53% of the discharged barium. Multiple regression analysis suggested excess sediment Ba distribution was largely controlled by water depth.

The total excess Ba within 500 m of these sites was highly correlated with the total Ba used at the site. Thus, the effect of multiple wells on near-site sediments is directly additive. Discriminant analysis suggested that statistically significant ($\geq$ twice background levels) Ba enrichment existed in surface sediments at 25 of the 30 control (3,000 m) stations studied. Ba levels at "control" sites were up to 4.5 times subsurface background levels. Statistically significant elevations in sediment mercury concentrations within 125 m of the site (4-7 times mean control levels) were observed at the Vermillion 321 and High Island sites (both deep water sites) and were strongly correlated to Ba levels. The High Island site also showed a significant Pb gradient, showing mean levels within 125 m 5-fold higher than controls and 3.8-fold higher within 500 m; Pb was highly correlated with Ba at this site. Other study sites exhibited patchy distributions of elevated sediment Pb levels, but no consistent spatial trends.

Sediment levels of Cd, Cu, and Zn were determined in only 9 or 10 surficial samples at each site, so evaluations were tenuous with such small sample sizes. Observations made included the following. Cd appeared elevated at the High Island and Vermillion 321 sites and was correlated to Ba at the Vermillion site. Cu showed no consistent trend at any site except for small elevations within 125 m at the High Island site, and was correlated to Ba. Zn showed consistent gradients at the High Island and Vermillion 321 sites, with elevation 5-10 times control levels, and was correlated to Ba and distance at both sites. Within 250 m of the Vermillion 321 and High Island sites, 4- to 5-fold elevations of hydrocarbons over control station levels were observed. However, among the six (all gas) platforms, hydrocarbon contamination was generally low.

Continental Shelf Associates, Inc. and Barry A. Vittor and Associates, Inc. 1989a. Environmental Monitoring in Block 132 Alabama State Waters, Summary Report. Prepared for: Shell Offshore, Inc.

The program objective as presented in this report was to determine whether or not drilling discharges affected the biotic assemblages living in the vicinity of the discharge site. The program consisted of three sampling elements: 1) continuous recording of near-bottom current speed and direction; 2) analysis of surficial sediments collected within 1,000 m of the discharge site for sediment grain size, trace metals, and oil and grease; and 3) sampling and analysis of macroinfaunal assemblages present within 1,000 m of the discharge site.

Sampling was conducted during four surveys: Survey 1, prior to drilling discharge; Survey 2, two months after drilling discharges commenced; Survey 3, five days after drilling discharges ceased; Survey 4, eight months after drilling discharges ceased. The sampling pattern consisted of eight radials centered at the discharge site and oriented toward north, northeast, east, southeast, south, southwest, west, and northwest. Stations were located along each radial at 122 m, 500 m, and 1,000 m. In addition, four stations were located at 91 m on the four primary radials, i.e., north, east, south, and west. The analyses conducted were: 1) sediment grain size analyses; 2) chemical analyses; and 3) analyses of biological samples.

Near bottom currents predominantly flowed southeastward and, to a lesser extent, northwestward. Sand predominated at many of the stations in the study area on all four surveys. However, sediments did appear to become progressively finer as the program progressed. The authors found that changes in sediment grain size resulting from drilling discharges could not be easily separated from non-drilling-related changes. They concluded that changes observed within 122 m of the discharge site were probably related to drilling discharges. Changes of similar magnitude were observed by the authors farther away, but were thought due to non-drilling-related causes based on examination of the barium distribution.

The authors analyzed for 10 trace metals (aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, and zinc) and oil and grease at 16 stations located within 1,000 m of the discharge site on the four surveys. Their results showed that except for barium, the trace metal concentrations in the whole-sediment samples were correlated with the quantity of fine-grained particles in the sediments. Their analysis of the mean concentrations of Ba in the fine-grained fractions were shown to be consistently greater during survey 3 compared to Survey 1 at all stations located within 1,000 m of the discharge site where trace metal concentrations were determined. During Survey 4, only one of the sixteen stations was statistically greater than during Survey 1.

The study states that changes in other trace metals concentrations did not appear related to drilling discharges. The concentration ranges of aluminum, arsenic, cadmium, chromium, copper, lead, and mercury in whole sediments were within or near ranges reported in previous studies conducted in offshore Alabama waters. The authors' statistical analysis revealed no changes that were attributable to drilling discharges.

The authors found that the mean mercury concentrations in fine fractions during Surveys 2 and 3 were statistically greater than those observed during Surveys 1 and 4. It was concluded that mercury concentrations were not positively correlated with barium concentrations and therefore, probably not associated with discharged barite.

At each of the four surveys, the authors collected ten replicate samples, at each of 16 stations, and analyzed them to determine the composition of the macroinfaunal assemblage. The macroinfaunal assemblage summary parameters (number of taxa, density, diversity, evenness, and species richness) were calculated for all stations and surveys. The values of these parameters were within ranges expected for this area and were related to sediment grain size, but not to proximity to the discharge site. Considerable temporal and spatial variability was observed by the authors.

The authors used species cluster analysis and dendrograms to reflect the presence of assemblages typical of nearshore sand and silt habitats throughout the northern Gulf of Mexico. The authors grouped stations in the clustering analysis primarily on the basis of time of sampling, and not by sediment texture or distance from the discharge site. Using canonical descriminant analysis of environmental factors such as time, distance from the drill site, sediment texture, and trace metals, they indicated that benthic station groupings were determined primarily by season and not by distance from the discharge site or by drilling discharge tracers such as barium or percent clay. They found that sediment texture (percent gravel) did account for a small amount of the variability among station groups.

The study concludes that the number of macroinfaunal taxa was not related to either sediment texture or distance from the discharge site. Individual abundance was correlated with sediment texture and varied with season, but was not related to distance from the discharge site. Species diversity (H') was relatively uniform temporally and spatially. The authors indicated that the observed changes reflect the effects of sediment texture and season on numbers of individuals, and are not related to distance from the discharge site. Evenness and species richness levels varied with sediment texture and showed temporal changes. These parameters were not related to distance from the discharge site.

Continental Shelf Associates, Inc. and Barry A. Vittor and Associates, Inc. 1989b. Environmental Monitoring to Assess the Fate of Drilling Fluids Discharged into Alabama State Waters of the Gulf of Mexico. prepared for: Offshore Operators Committee.

The purpose of this study was to determine whether drilling fluids discharged into Alabama State Waters outside of the barrier islands can be detected in statistically significant levels in areas of biological concern located inside the barrier islands. To accomplish this goal, the study was divided into two monitoring efforts: area-wide monitoring and drill site monitoring. The area-wide effort involves two principal elements: 1) sampling and analysis of surficial sediments at 12 stations for grain size, oil and grease content, and concentrations of 10 trace metals; 2) sampling and analysis of oysters for the same metals at three of the surficial sediment stations. The report summarizes methods and results of area-wide sampling from Survey I (February 1986) through Survey VI (June 1988).

Beginning between Surveys IV and V, an exploratory well was drilled in Alabama State waters Block 132. Between October 9, 1987 and February 29, 1988, approximately 7,285 m^3 of drilling fluids and 726 m^3 of cuttings were discharged. About 79% of the total volume was discharged between October 9 and November 6, 1987 (i.e., prior to Survey V).

In addition to the drilling activity, a major dredging project began during the interval between Surveys IV and V. Dredging of the Mobile Bay ship channel began in January-February 1987, when about 500,000 m^3 were dredged. Dredging resumed in October 1987 (two months before Survey V) and was expected to continue until February 1990. About 23,000 - 31,000 m^3 were dredged per day, with all of the material being placed in the offshore disposal area outside of the barrier islands.

Also, the data set from drill site monitoring in Block 132 can aid in the interpretation of the area-wide data set by indicating which variables might be affected by drilling discharges. For example, if the concentration of a metal were unaffected near the drill site, then changes in the concentration of the metal in Mobile Bay (where the nearest station is 10 km from the drill site) could not be attributed to drilling fluids from the well.

Ba concentrations increased substantially around the drill site in Block 132 during drilling. Statistically significant increases in Ba concentrations were detected to a distance of 500 m from the drill site, and apparent two to five-fold increases in mean Ba concentration were evident at four 1,000 m stations (though not statistically significant).

Eleven of the 12 stations monitored in Mobile Bay during this study showed no significant increases in fine fraction Ba concentration or barium-to-iron ratio. At Station 3, the mean of the Survey V-VI values (318 mg/kg) was about 13% higher than the mean of the Survey I-IV values (282 mg/kg), and was statistically significant.

This small increase in barium at Station 3 was thought probably due to natural variability rather than drilling fluids. No significant increases were observed at four other stations located between Station 3 and the mouth of the bay, where the drilling fluids would enter. Three of these stations had much higher silt/clay content than Station 3 and were thought more likely to retain fine drilling fluids deposits.

Increases in concentrations of some metals other than barium occurred around the drill site in Block 132. Changes in cadmium and mercury concentrations between surveys were detected, but these were not attributed to drilling discharges because the changes were spatially uniform and were not correlated with barium increases. Significant increases in arsenic (one station), copper (one station), and zinc (one station) were detected, but were attributed to natural sediment movement or sampling/analytical error associated with the small quantities of fine sediment available for analysis from one station.

In the area-wide sampling, there were several significant increases in concentration and/or metal-to-iron ratio for metals other than barium. Cadmium had the highest number of significant differences (seven stations), followed by arsenic (four stations). Significant differences were also detected for chromium (Station 12), and lead (Stations 3 and 9). In plots of station means, large increases between Surveys V and VI were noted for cadmium, copper and lead at Station 3, and copper at Station 9. The copper increases were not significant in the statistical analysis, which used the mean of Surveys V-VI.

Increases in concentrations of these other metals were thought probably not due to drilling fluids. All of the metals except aluminum and iron, which are normally associated with clay particles, are present in drilling fluids primarily as trace contaminants of barite. Because barium is more concentrated in drilling fluids (relative to normal sediments) than the other metals, increases in these other metals due to drilling fluids were expected to be accompanied by major increases in Ba. No such increases were seen during the study.

Oil and grease concentrations increased significantly at Stations 2, 5, 6, 7, 8, and 11 between Surveys II-IV and Surveys V-VI. The increase at Station 11 can be attributed to an increase in silt/clay content of the sediments (oil and grease concentrations tended to be higher in sediments containing more silt/clay). The explanation for the other increases were not known, but were thought probably not due to drilling fluids, because there were no accompanying increases in barium concentration.

Drilling fluids discharged to the ocean may contain small amounts of hydrocarbons, although they are subject to the test of "no visible sheen". At stations around the drill site in Block 132, there were some apparent increases in sediment oil and grease content during drilling, but these appeared to be related to natural sediment changes as indicated by whole sediment aluminum concentrations.

There were no statistically significant increases in the concentrations of 8 and 9 metals in oyster tissue. Arsenic concentrations in both depurated and non-depurated oysters were significantly higher on Surveys V-VI than on Surveys I-IV. The temporary increase in arsenic concentration in oyster tissue probably is not due to drilling fluids. There are no oyster data from the drill site monitoring in Block 132, because no oysters were present there. However, arsenic concentrations in drilling fluid were no higher than those in the fine fraction of sediments from Mobile Bay. The reason for the temporary increase in arsenic concentrations in oysters is not known.

A statistical difference between Surveys V-VI and Surveys I-IV does not necessarily indicate an effect of drilling. Some significant differences could reflect natural changes that did not occur during the previous year of “baseline” sampling. Other differences could be due to the channel dredging project, which began between Surveys IV and V and which continued through the monitoring program. Unfortunately, conditions in the real world are seldom ideal in the sense of a controlled experiment.

The reason for increases in metal concentrations between Surveys I-IV and Surveys V-VI was not known. Possible explanations included the following:

- The first four surveys did not encompass the full range of non-drilling related variations in trace metal concentrations. Such variations may be attributed in part to natural seasonal and year-to-year fluctuations.

- The channel dredging project.

- The fine fraction at predominantly sandy stations may be different from the fine fraction at silt/clay stations, or more prone to analytical error; stations with high percentages of sand had highly variable metal concentrations or metal-to-iron ratios on one or more surveys and support this hypothesis.

Continental Shelf Associates, Inc. 1989. Pre-drilling and Post-drilling Surveys for Pensacola Area Block 996. Prepared for Texaco Producing Inc.

A monitoring study of a single exploratory well located in approximately 60 m water depth was conducted in Pensacola Block 996 to detect any obvious impacts to the hard bottom epibiotic community of nearby live-bottom areas. The study involved collected pre-drilling and post-drilling video and quantitative still camera data, as well as post-drilling surface sediment chemistry data. Drill site sediment Ba levels at 3 stations within 250 m of the discharge, expressed as either bulk phase or fine-fraction values, were 40-125 times greater than the average reference station value (which in turn was about twice the reported background level). Sediment barium levels (bulk and fine fraction) at 2000 m averaged twice the reference station levels. Bulk phase sediment chromium levels were only elevated at the drill site; fine-fraction chromium levels were 50% and 20% above reference levels at 250 m and 500 m, respectively.

Background was defined at three reference stations located approximately 3,500 m from the drill site. However, reference station values must be regarded with caution for three reasons: 1) predrilling samples were not taken, 2) values obtained in the post-drilling survey (45-70 ppm Ba; 19-22 ppm Cr) were substantially higher than an earlier, nearby baseline conducted prior to drilling (29 ppm Ba; 3 ppm Cr), and 3) a continuous distance-dependent decrease in bulk and fine-fraction Ba and fine-fraction Cr occurred to the farthest radial array stations, including the reference stations.

Only “catastrophic, large-scale changes (e.g., complete mortality)” would be detectable from the photographic and video data collected. No such “catastrophic” effects were observed. Overall, photographic data from stations within 2,000 m of the drill site showed a 55% decrease in total biotic coverage for pre- versus post-drilling surveys; reference station values decreased 19%. Overall decreases, at both drill site and reference stations, were primarily due to dramatic (i.e., 95%) decreases in bryozoan coverage between surveys.

This study presents a typical picture of what exploratory well impacts will be on sediment chemistry. The significant confounding factor here is the “true” background level of Ba and Cr. If the earlier study values are used as reference values, then sediment Ba levels are elevated four-fold at 2 km, and sediment Cr values are 8- to 10-fold higher within 500 m of the discharge. This range of values is expected for these types of discharges.

Steinhauer, M. et al. 1990. California OCS Phase II Monitoring Program Year-Three Annual Report. Chapter 13. Program Synthesis and Recommendations.

The California Outer Continental Shelf (OCS) Phase II Monitoring Program (CAMP) study is a good example of the difficulties inherent to marine impact assessment. The specific objectives of CAMP were:

- To detect and measure potential long-term (or short-term) chemical, physical, and biological changes in the benthic environment around development platforms in areas of soft-bottom and hard-bottom substrates in the southern Santa Maria Basin.

- To determine whether the changes observed were caused by drilling-related activities or whether they were the product of natural physical, chemical, and biological processes in the study area.

The study area is on the southern portion of the Santa Maria Basin OCS. All but one station were located at water depths ranging from 90 m to 410 m. At the soft-bottom site, a semi-radial array of stations was located around the proposed future site of Platform Julius in water depths raging from 123 m to 169 m. At the hard-bottom site, stations were located on high- and low-relief hard features, and in adjacent soft-sediment locations in 105 m to 213 m of water near the site of Platform Hidalgo.

In the development of CAMP, its design explicitly addressed the importance of taking synoptic measurements from replicate samples and keeping replicate data separate. Also, in the absence of pre-impact sampling it could be argued that control sites and impacted sites always differed and, in the absence of control sites, it could be argued that change at impacted sites was not caused by the impact. CAMP's design also employed an optimal-impact study design, with pre-impact as well as post-impact sampling, and control site as well as impacted site sampling.

Postponement of platform emplacement and drilling at the soft-bottom site and an abbreviated drilling schedule at the hard-bottom site necessitated changes in the scope and schedule of the monitoring program. Monitoring at the soft-bottom site was thought to provide valuable baseline information on physical, chemical, and biological features and processes in the area. This information was thought to be valuable in the design and execution of future monitoring studies of platform discharges when the platform is installed at the Julius site.

Although the soft-bottom components of the monitoring program were prematurely concluded due to a lack of industry activity, certain aspects of the monitoring design were believed useful. Biological data supported the idea that meaningful levels of change could be detected for dominant species and for more encompassing parameters such as diversity. Chemical data supported the idea that barium could be used as a tracer of activity in spite of high, but invariate, natural levels in the region.

Data representing different sampling occasions provided evidence of significant temporal variation in both the macrofauna and meiofauna. Within-year variations, although significant, did not follow the same patterns consistently from one year to the next. Nevertheless, these results were taken to demonstrate the importance of conducting repeated sampling before and after initiation of drilling activities, to provide a basis for differentiating between natural temporal variations in benthic community parameters and impacts caused by drilling and production activities.

Monitoring at the hard-bottom site near Platform Hidalgo provided information on platform effects and on discharges associated with drilling of seven wells between November 1987 and January 1989. The original hypothesis for determining platform-related effects established two major criteria: 1) a before-and-after farfield/nearfield effect (i.e., space-time interaction) and 2) a change in organism abundance correlated to the dose of drilling wastes (relative flux of chemical signals, from sediment trap data). Of the 10 species tested for a time-space interaction, only the solitary coral, *Caryophyllia* sp., showed such an effect. Due to an incomplete data set from the sediment trap fluxes at the three stations where a significant time-space interaction was observed for this species, data are only available for a limited period (November 1987 and October 1988).

There were insufficient number of stations to calculate an analysis of variance with depth and time as additional covariates. Given these limitations, together with those of limited data from the sediment traps, the best test of a platform-related effect on *Caryophyllia* were scatter diagrams. Neither total sediment flux nor total PAH concentrations were related to the effect, although in both cases one station that showed a loss of *Caryophyllia* cover between 1987 and 1988 had a slightly greater relative flux of these materials. However, tests of the relationship between *Caryophyllia* sp. abundance in a larger data set indicated a highly significant relationship between sediment flux and species abundance.

These data would seem to support a hypothesis of impact. However, the authors presented a disturbing analysis. Although the change in percent cover of *Caryophyllia* seems to support a conclusion of drilling-related impacts, it was noted that the change between sampling periods was less than 50 percent. the original power analysis indicated that, with a sampling replication of 60 photo-quadrants per station per time, the minimum change in the density of this species that could be detected with 95 percent confidence for 80 percent of the time was approximately 70 percent. This power analysis-to-effect comparison raises questions as to whether this effect in a single species was a chance event. The sampling error was greater than the range of the effect detected. Therefore, despite the time-space interaction and a relationship between dose and response, the authors concluded that significant doubts remain as to whether there was a real platform-related effect on this species.

CAMP monitoring data has revealed several variables that may limit the ability of any monitoring program to detect change related to oil and gas activity in the region. The densities and numbers of species with transect location has been shown to vary along all isobaths. Potential sources of hydrocarbons from natural seeps confound the ability to relate change to oil and gas activities. Fishing activities risk in-situ instrument deployments and also affect bottom communities. Finally, the difficulty of scheduling surveys to coincide with drilling activities for appropriate before-and-after comparisons is a basic problem in any monitoring program, and it has been shown in this program to be particularly difficult to control.

9.3.2 *Synthetic-Based Fluids*

Smith, J. and S.J. May. 1991. Ula Wellsite 7/12-9 Environmental Survey 1991. A report to SINTEF SI from the Field Studies Council Research Centre. November 1991.

This paper is the second in a series of three lead by Janet Smith, identifying the results of yearly sampling at the Ula well site 7/12-9 in the North Sea. This paper also includes a comparison of the 1990 to 1991 results. The authors report that sampling was conducted one year after the discharge of an ester-based drilling fluid. The sample stations were along two transects, one to the southwest (SW) and one to the southeast (SE), with distances from the discharge location of 50, 100, 200, 500, 800, 1,200, 2,500, and 5,000 m to the SW and 100, 200, 500, and 1,200 m to the SE. A reference station was located 6,000 m to the northwest of the discharge point. The ten replicate samples taken at this reference station were "treated as two sets of five replicates to make data analysis easier," and are referred to as Ref. A and Ref. B. Samples were taken for total hydrocarbon (THC), ester, metals, grain size analysis, and biological analysis.

THC reported for the 1990 samples were highest at 200 and 500 m to the SW and 100 and 200 m to the SE. These THC levels were reported at 774 and 86.4 mg/kg for the SW stations and 184 and 205 mg/kg for the SE stations, respectively. The THC levels for the 1991 survey were dramatically reduced to 13.6, 5.9, 64.0, and 3.8 mg/kg for same stations listed above. Although there was an increase in THC levels for the 50 and 100 m SW stations, it was not above background levels measured at the reference station. There was an overall decreasing trend for the THC concentration from 1990 to 1991.

The ester concentrations reported in 1990 were 85,300, 46,400, and 208 mg/kg for the 50, 100, and 200 m SW stations, respectively. The reported ester values for these stations for 1991 dropped to 0.21, 0.22, and 1.34 mg/kg, respectively.

Barium concentrations for 1990 were reported highest at the 50-200 m SW and 100-200 m SE stations. There was an increase in Ba concentration along the SW transect from 1,720 to 2,890 mg/kg, out to 200 m. The Ba concentration decreased along the SE transect, with the highest level of 3,770 mg/kg at 100 m. There was an overall decrease in 1991 Ba levels.

The authors also report dramatic changes in the benthic communities from 1990 to 1991 as summarized in Exhibit 9-7. Although one station showed an increased abundance of the opportunistic *C. capitata*, this isolated instance of taxonomic indicator of stress was not taken to demonstrate any generalized impact had occurred from the discharge of this material.

Exhibit 9-7. 1990 and 1991 North Sea Benthic Community Data

Sample Station	Taxa		Individuals	
	1990	1991	1990	1991
50 m SW	4	51	16	379
100 m SW	7	44	167	370
100 m SE	35	52	234	405
Reference A	66	48	385	340
Reference B	53	58	356	329

Candler, John E., S. Hoskin, M. Churan, C.W. Lai, and M. Freeman. 1995. Sea-floor Monitoring for Synthetic-Based Mud Discharged in the Western Gulf of Mexico. SPE 29694 Society of Petroleum Engineers Inc. March 1995.

The authors monitored the fate and effects of discharged SBF and associated cuttings (SBF-cuttings). The authors measured the fate of the polyalphaolefin (PAO) on three sampling cruises to an oil platform that had discharged SBF-cuttings consisting of 441 bbl of cuttings and 354 bbl of adhering SBF. The cruises were conducted nine days, eight months, and 24 months after the discharge had stopped. The effects of the SBF and cuttings on the benthos were measured only on the third sampling cruise. The sampling grid was a series of stations along two perpendicular transects running in north/south and east/west directions from the discharge point. The sampling stations were located along each of the transects at distances of 25 m, 50 m, 100 m, and 200 m from the discharge point. Samples from 2,000 m were used as reference points. The authors used chemical analysis for barium, total petroleum hydrocarbons (TPH) and oil and grease (O&G) to determine the presence of PAO base fluid in sediment samples. The authors stated that TPH was the better of the two organic analyses for detecting the synthetic material because the TPH test excludes certain polar organic compounds (e.g., fatty matter from animal and vegetable sources) often detected in O&G tests. Effects on the benthos were determined by a community analysis system which measured the species richness (number of taxa), evenness (how equally the total number of organisms is distributed), and diversity (measure of interaction of richness and evenness).

The authors indicated that the greatest initial distribution of TPH, as measured nine days after discharge, was along the north/south transect with maximum values of 39,470 mg/kg (3.9 percent) at 100-m north and 134,428 mg/kg (13.4 percent) at 50-m south. In addition, TPH was initially measured above 1,000 mg/kg in all four directions with the furthest locations of 100-m south and 200-m north. The results from the second sampling survey (eight months later) indicated a decrease in average TPH for all distances except at 25 m. There was an increase in average TPH at 25 m predominately to the south and west (from 203 to 7,283 and 2,827 to

25,747 mg/kg, respectively), indicating a southwesterly drift in the sediment. Results from the third and final sampling survey (24 months later), while indicating a decrease in the average TPH at 25 m, also indicated an increase in TPH at all but one of the four 25-m stations. The decrease of the west 25-m station (from 25,747 to 8,330 mg/kg) overshadowed the increase of TPH at the other three stations. Two stations beyond 25 m (50-m south and west) each measured an increase to greater than 1,000 mg/kg TPH.

Although not discussed by the authors, the chemical analysis for the third survey indicated an increase or no change in TPH for 10 of the 16 stations within 200 m of the discharge. There was a slight increase in TPH for the 2,000-m west reference station. Sediment TPH and barium data suggest little degradation of PAO (as indicated by TPH) between the second and third surveys, although migration of fluids to further stations may be occurring. Exhibits 9-8 and 9-9 present average PAO (as indicated by TPH) and Ba levels versus distance for these surveys.

The benthic analysis, at 24 months after SBF-cuttings discharge terminated, indicated three sample stations that were significantly different than the reference stations. These three sample stations were 25- and 50-m south and 25-m west from the discharge location. The highest TPH values were also measured at these three stations. The variability for species richness, abundance, diversity, and evenness was reported to be much higher among all sample stations within 200 meters of the discharge site than the variability among the reference stations.

Schaanning, M. 1995. Evaluation of Overall Marine Impact of the Novadril Mud System. NIVA Report 0-95018.

This report reviews available laboratory data on the toxicity, bioaccumulation, and biodegradability of three types of polyalphaolefin (PAO)-based SBF. The report compares the finding of experimental studies on PAOs to field surveys of ester- and ether-based synthetic muds. The author cites results of Smith and Moore (1990) and Smith and Hobbs (1993), in which three surveys were conducted at the Ula well site 7/12-9 in the North Sea in 1990 immediately after discharge of 97 tons of synthetic esters ceased, in 1991 one year later, and in 1992 two years later. Sampling pattern information for these surveys is given in the summary of Smith and May (1991).

Schaanning reports that during the 1990 survey, the maximum concentration of synthetic ester detected was 85,300 mg/kg at 50 m from the well. The average concentration of synthetic ester for eight sample sites (between 0 and 1 km; no further detail provided) was 16,546 mg/kg compared to 2.3 mg/kg at a reference station 5,000 meters distant. Benthic organisms were severely impacted out to 100 m. Schaanning reports that in 1991 and 1992, the maximum

Exhibit 9-8. Sediment TPH vs. Distance from Drill Site

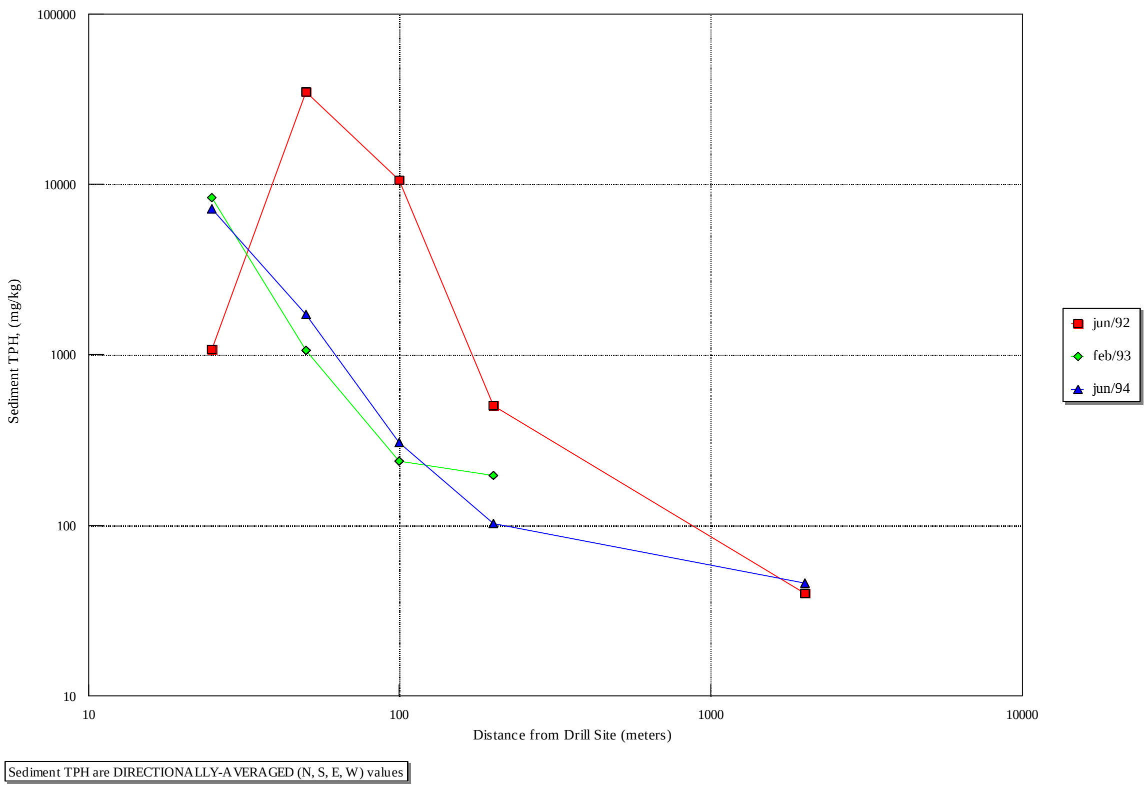
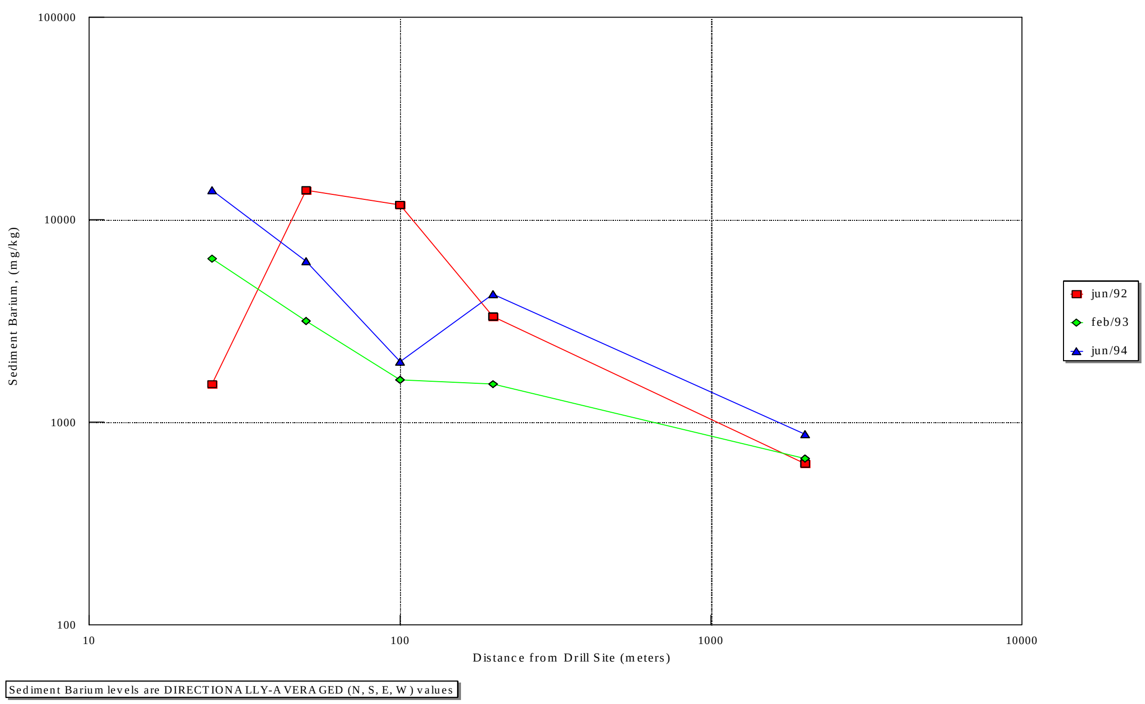


Exhibit 9-9. Sediment Barium vs. Distance from Drill Site



concentrations of synthetic ester base fluid were 11.7 and 0.38 mg/kg, respectively. In 1991, the average ester concentration at eight stations within 1,000 m of the drill site was 2.5 mg/kg, approximately 10-fold higher than that at a reference station 6,000 m distant from the drill site. In 1992, the average ester concentration at eight stations within 1,000 m was 0.24 mg/kg, approximately 3-fold higher than at the reference station 6,000 m distant. Schaanning reports other multivariate analyses of benthos (Smith and Hobbs, 1993) provided evidence that minor changes to the macrobenthic communities were still present two years after the discharge ceased.

Schaanning also cites a three-year study by Bakke et al. (1992) of a discharge of cuttings contaminated with an ether-based SBF. The surveys were conducted at the Gyda well site 2/1-9, just after the discharge of 160 tons of ether SBF ceased and annually for the next two years. Bakke reports that the maximum concentrations of synthetic ether at 50 m southwest from the platform were 2,600, 14,700, and 3.7 mg/kg for 1991, 1992, and 1993, respectively. The mean concentrations for the stations between 100 and 200 m from the platform for 1991, 1992, and 1993 were 236, 96, and 2.1 mg/kg ether, respectively. Although no benthic data are presented for the four stations at which benthic biota were analyzed, Bakke reports benthic impacts were "remarkably weak" for the high concentration of synthetic ether detected in 1992.

It should be noted that Schaanning includes brief discussions of additional seabed studies, which are not referenced to studies or reports, from the North Sea. The information presented from these studies is limited and does not include any quantitative results from benthic analyses.

Daan, R., K. Booij, M. Mulder, and E. Van Weerlee. 1996. Environmental Effects of a Discharge of Cuttings Contaminated with Ester-Based Drilling Muds in the North Sea, Environmental Toxicology and Chemistry, Vol. 15, No. 10, pp. 1709-1722. April 9, 1996.

The authors conducted field surveys in the Dutch sector of the North Sea for the effects of discharged drill cuttings contaminated with an ester-based fluid over an 11-month period. A total of 181 metric tons of ester (in a total estimated amount of 477 tons of an ester-based SBF) was discharged. Three sampling surveys were conducted 1, 4, and 11 months after the drilling was completed. The authors also conducted a background survey prior to drilling to determine natural variations of macrofauna and background chemistry. This background survey was conducted prior to platform placement along a northeast-southwest transect that followed local residual current patterns, with station located from the well site at distances of 75, 200, 500, 1,000, and 3,000 m to the NE, and 75 m to the SW. However, because of the changes in sediment type beyond 200 m, this transect was not used in the post-drilling surveys. The first post-drilling survey was conducted one month after ester-based SBF discharges ceased to determine ester base fluid concentrations only and was sampled northward from the drill site at distances of 75, 125, and 200 m to the N, then 75 m to the NE of the well site. There were no benthos samples taken during this survey. The second and third post-drilling surveys occurred four and 11 months after ester-based SBF discharges ceased. Both surveys included benthos and chemistry samples taken at 75, 125, 200, 500, 1,000, and 3,000 m to the N, at 75, 125, and 200 m to the NE, and at 75 m to the SW.

The chemical analysis for the three post-drilling surveys indicated the ester base fluid was confined to distances under 200 m from the well site. Once beyond the 200 m station, ester base fluid concentrations were at background levels. However, the analysis also showed an increase in the ester base fluid from the one- to four-month surveys for all distances out to 200 m. Analyses from the 11-month survey indicated a sharp decline in ester base fluid at all stations.

Sediment grain size distributions and benthic macrofaunal abundance from the background survey indicated similar communities occurred only out to 200 m. As a result, benthos background results used for analysis were limited to stations at 75, 125, and 200 m from the discharge location. The benthic analysis from the second survey indicated effects out to 500 m from the well site and was attributed to the echinoderm *Echinocardium cordatum*. Ecordatum is highly sensitive to organic enrichment and living adults were found up to 500 m from the well site. Additionally, a bivalve that was one of the dominant species at 500 m was not found at the closer stations. There was a gradual increase in species abundance with distance. When compared to the background levels, the species abundance beyond 500 m after four months was lower, but the authors attributed this to seasonal fluctuations. Benthos analysis from the third post-drilling survey at 11 months indicated significant impacts out to 200 m. The authors indicate that species abundance, while significantly different from the reference stations, showed recovery of the sediments was apparent after 11 months.

BP Exploration Operating Company Ltd. 1996. BP Single well 15/20b-12 (Donan) synthetic mud (Petrofree) second post-drilling environmental survey. Environment & Technology Ltd. ERT Draft Report No. 96/062/3 June 1996.

This survey was the second of two surveys at the BP single well site 15/20b-12, located in the North Sea. Although the first survey was not available for review, this second report compared the 1995 and 1996 seabed survey results for this well site. The first survey was conducted in August 1995 approximately 5 months after drilling shutdown. The second survey was conducted in June 1996, 15 months after drilling shut down. The discharge of Petrofree, an ester SBF, amounted to 304 metric tons and was discharged at a depth of 142 m. The observations taken by the authors were: 1) Side-scan sonar for cutting depth (piles), 2) Petrofree base fluid concentrations in 0-2 cm, 2-5 cm, and 5-10 cm of sediment, 3) barium concentrations, 4) redox measurements at 2 cm and 4 cm, and 5) biota . Sampling sites were at 25-5,000 m down-current (South) from the platform, 25-200 m up-current to the North, and 25-100 m to the East, West, Northeast, Northwest, and Southwest.

The 1995 survey indicated the highest concentration of Petrofree in the surface sediment (0-2 cm) was located within 25 meters of the platform. The sampling point with the highest concentration was 25 m Southwest, with an ester concentration of 8,389 mg/kg. Concentrations within 25 meters of the platform ranged from 1,055 to 8,389 mg/kg. The highest concentration at the furthermost station was 105.5 mg/kg at 200 meters north of the platform. The concentrations of Petrofree (base fluid) within 2-5 cm of sediment within 25 m ranged from 8.4 to 1,935 mg/kg. The concentrations of Petrofree within 5-10 cm of sediment within 25 m ranged from 0.9 to 105.3 mg/kg. Petrofree was measured at a concentration of 1,081 mg/kg in 10-15 cm subsurface sediment at 25 meters north. Barium concentration ranged from 70,100 mg/kg at the center to 661 mg/kg at 1,200 m south. Redox and side-scan sonar results for 1995 were not reported. Although data are not given for effects on benthic communities for the 1995 survey, the report indicated that the number of species, evenness, and diversity were statistically significant in relation to Petrofree concentration and distance.

The 1996 survey indicated lower concentrations for surface sediment (0-2 cm) for most sample sites. The authors reported changes ranging from 1.1-fold lower concentrations to 13.5-fold lower concentrations from 1995 to 1996. Sediment concentration of Petrofree ranged from 133.1 to 1,785 mg/kg for the 25 m range. The highest concentration at the furthermost point was 0.1 mg/kg measured at 500 m south. Variability among subsurface sediment (2-5 and 5-10 cm) Petrofree concentrations prevented development of trends for subsurface concentrations. Barium concentration ranged from 22,000 at the center to 572 mg/kg at 1,200 m south. Redox readings indicated anaerobic conditions within 200 meters of the platform. The depth profile indicated cutting piles of up to 15 cm out to 50 meters from the platform. Biota measurements indicated clear impacts at 50 m, with transition communities developing between 100 to 300 m. The authors stated the benthic communities at 1,200 meters indicated impacts associated with industrial activity and trace amounts of Petrofree were measured at that location.

Vik, E.A., S. Dempsey, B. Nesgard. 1996. Evaluation of Available Test Results from Environmental Studies of Synthetic Based Drilling Muds. OLF Project, Acceptance Criteria for Drilling Fluids. Aquateam Report No. 96-010.

The authors provided a summary of results from eleven seabed studies, three of which have been separately reviewed in this report. Many of these reports were unavailable in English. The authors presented a short review of sampling grids, discharge volumes, discharge depths, and results. The information provided by authors was limited for each seabed survey and the results are included in Exhibit 9-2. However, a critical review of each original report has not been provided in this Environmental Assessment. The overall trends of these reports were: (1) concentrations decreased with distance from discharge point; (2) concentrations measured were not discharge volume dependent; and (3) concentrations decreased with time, although there were a few instances where the concentrations actually increased.

Continental Shelf Associates, Inc. 1998. Joint EPA/Industry Screening Survey to Assess the Deposition of Drill Cuttings and Associated Synthetic Based Mud on the Seabed of the Louisiana Continental Shelf, Gulf of Mexico. 21 October 1998, Data Report. Prepared for API Health and Environmental Sciences Dept.

The authors provided a data report on a joint EPA/Industry screening cruise, which was conducted to provide a preliminary evaluation of the areal extent of observable physical, chemical, and biological impacts of drill cuttings contaminated with SBFs (SBF-cuttings) and to evaluate sampling methods that will be used in future more detailed surveys. Three sites were surveyed for organics (SBF associated hydrocarbons, TOC and PAH), sediment grain size, odor and visual characteristics, and water column profiles. Oxidation-reduction potential, macrofauna and sediment toxicity samples were taken at selected sites. Side-scan sonar and Benthos MiniROVER remote operated vehicle (ROV) television camera were used to identify accumulation of drill cuttings. Sampling sites were located on a radial grid and along four transects that were parallel with bathymetry when possible. The stations were at distances of 50, 150, and 2000 m from the platform, with the 2000 m stations serving as the references stations. Two additional stations, 100 m from the platform, were sampled at two of the sites. The highest concentration of SBF associated hydrocarbons (1,900, 6,500, and 23,000 mg hydrocarbon/kg dry sediment) were found within 50 m of the platforms. The furthermost station at which SBF-associated hydrocarbons were found was 100 m for one platform. The concentration measured at that one station was 41 mg hydrocarbons/kg dry sediment. Nine sediment samples were also taken for sediment toxicity tests using the 10-day sediment toxicity test (ASTM E 1367-92; ASTM, 1992). Two of the nine sediment samples taken would have been considered toxic to marine amphipods using the current sediment testing guidelines. Percent survival of amphipods exposed to those two samples was 77% and 62%. SBF associated hydrocarbons were not measurable at the detection level for these two samples. Analyses of impacts to marcofauna were not complete at the time of this report. Conclusions drawn by the authors were elevated concentrations of SBF-associated hydrocarbons were scattered around the platform rather than in a continuous pattern; side-scan techniques could be improved; ROV use is not appropriate near soft muddy seafloors; and a better methodology for evaluating electrochemical potential (Eh) is needed.

EPA also gathered samples for duplicating testing, and is also holding samples for macrofaunal enumeration. EPA has not yet completed its analyses and evaluation. EPA intends to complete this work and report the results in the future.

LGL Ecological Research Associates, Inc., 1998. Opportunistic Sampling at a Synthetic Drilling Fluid Discharge Site on the Continental Slope of the Northern Gulf of Mexico: the Pompano Development, 10-11 July 1997 and 13-14 March 1998. Prepared for BP Exploration, Inc.

The authors conducted two benthic studies to assess the impacts of the discharge of drill cuttings contaminated with the SBF Petrofree LE (a 90% LAO/10% ester blend) on benthic communities in 565 meters water depth. The studies were conducted 9 months apart with the first (July 1997) conducted 4 months after discharge ceased. Prior to this July survey, 6,263 bbls of SBF had been discharged. An additional 1,486 bbls of SBF was discharged for 2 months prior to the second survey in March of 1998. The surveys analyzed benthic sediment samples for both chemical concentrations of Petrofree LE and changes in benthic communities along four transects (NE, SE, SW, and NW). Sampling stations were located at 25 m intervals with the SW and NE transects extending to 75 m and the NW and SE transects extending to 50 m. As a result of chemical analyses from the July 1997 survey, the NW transect was extended to 90 m during the March 1998 survey. Samples for chemical analysis were divided into surficial samples (0-2 cm) and subsurface samples (2-5 cm).

Chemical analyses results for both surveys indicate the highest concentration of SBF for both surficial and subsurface samples were found along the NE transect and were located at the 75 m station. Concentrations of SBF at this location for the surface samples were 165,051 mg/kg for 1997 and 198,320 mg/kg for 1998. Concentrations at these locations for subsurface samples were 8,332 mg/kg for 1997 and 85,821 mg/kg for 1998. The authors suggest the possible reasons for high concentrations of SBF may be due to slower biodegradation rates than those noted in the North Sea or the initial concentration of Petrofree LE was higher than that measured. There were no statistical differences between the July 1997 and March 1998 surficial and subsurface concentrations. However, the March 1998 values were higher, lending some weight to the hypothesis that the initial Petrofree LE concentration was higher than measured.

Results of the March 1998 benthic survey indicate an increase of polychaetes and gastropods as compared to MMS background data. Polychaete densities were nearly 40 times higher than background data. Gastropod densities were nearly 3,000 times higher than background. The authors postulated that biodegradation may have sustained bacterial activity at a level that lead to an increase in these benthic macrofauna.